European Commission

EEAG revision support study

Final Report

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EEAG revision support study

Final report

Support study for the revision of the EU Guidelines on State aid for environmental protection and energy applicable in 2014-2020 (OJ C 200/1 of 28.6.2014) and the provisions applicable to aid for environmental protection (and energy) (Section 7) of the Commission Regulation (EU) 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty (General Block Exemption Regulation-GBER)

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Abstract

This report supports the European Commission's revision of the EEAG and section 7 of the GBER. It consists of 3 study items that address distinct questions:

Study Item 1: The measurement of cost-effectiveness (EUR per tonne of CO_2 avoided) allows for the assessment of relative decarbonisation benefits of policies, but may not always capture their overall environmental impact. Wind, solar and energy efficiency have similar cost-effectiveness, while cogeneration of heat and power is less cost-effective. Focusing on decarbonisation objectives only, multi-technology auctions improve cost-effectiveness by prioritising less costly technologies. If potential inframarginal rents and dynamic effects are also considered, then technology-specific auctions may exhibit lower carbon mitigation costs in some cases.

Study Item 2: Research on operating and investment aid is reviewed, with the finding that for environmentally friendly energy aid, some distortions have arisen from the nature of aid, but that both investment and especially operating aid can yield positive outcomes. Analysis of four actual schemes with operating or investment aid suggests that precise scheme design matters for success and often evolves with time. Three aid schemes are examined for industrial decarbonisation. Aid levels of 40% for fixed aid intensity are deemed unlikely, if the maximum aid intensities remain unchanged, to provide sufficient support for several industrial decarbonisation routes.

Study Item 3: Empirical studies support the relevance of electro-intensity and trade intensity for eligibility of energy-intensive users for levy exemptions in the EEAG. The analysis of levies from 2011 to 2018 highlights their large heterogeneity across sectors, countries and over time. Scenarios harmonising levies to the highest levy and abolishing exemptions lead to a substantial decrease in profits. A limited profit decrease is predicted when levies change by a percentage value, an absolute level or are partially harmonised to a threshold.

FR

Ce rapport soutient la révision des LDEE et de la section 7 du RGEC par la Commission européenne. Il se compose de trois éléments d'étude qui traitent de questions distinctes:

Premier élément d'étude: la mesure de l'efficacité des coûts (EUR par tonne de CO_2 évitée) permet d'évaluer les avantages relatifs des politiques en matière de décarbonisation, mais ne prend pas toujours en compte leur impact environnemental global. L'éolien, le solaire et l'efficacité énergétique ont un rapport coût-efficacité similaire, tandis que la cogénération de chaleur et d'électricité présente un moins bon rapport coût-efficacité. Si l'on se concentre uniquement sur les objectifs de décarbonisation, les ventes aux enchères multi-technologiques améliorent le rapport coût-efficacité en donnant la priorité aux technologies les moins coûteuses. Si l'on tient également compte des rentes infra-marginales potentielles et des effets dynamiques, les ventes aux enchères spécifiques à une technologie peuvent présenter des coûts d'atténuation des émissions de carbone plus faibles dans certains cas.

Deuxième élément d'étude: Les recherches sur les aides au fonctionnement et à l'investissement sont passées en revue. Il en ressort que pour les aides à l'énergie respectueuse de l'environnement, certaines distorsions sont dues à la nature de l'aide, mais que les aides à l'investissement et surtout au fonctionnement peuvent donner des résultats positifs. L'analyse de quatre régimes réels d'aides au fonctionnement ou à l'investissement suggère qu'une conception précise du régime est déterminante pour sa réussite et qu'elle évolue souvent avec le temps. Trois régimes d'aide à la décarbonisation industrielle sont examinés. Les niveaux d'aide de 40 % pour une intensité d'aide fixe sont jugés peu susceptibles, si les intensités d'aide maximales restent inchangées, de fournir un soutien suffisant pour plusieurs voies de décarbonisation industrielle.

Troisième élément d'étude: Les études empiriques soutiennent la pertinence de l'électro-intensité et de l'intensité commerciale pour l'éligibilité les utilisateurs énergo-intensifs aux exonérations de prélèvements dans le cadre des LDEE. L'analyse des prélèvements de 2011 à 2018 met en évidence leur grande hétérogénéité entre les secteurs, les pays et dans le temps. Les scénarios harmonisant les prélèvements au prélèvement le plus élevé et supprimant toutes les exemptions conduisent à une diminution substantielle des bénéfices. Une diminution limitée des bénéfices est prévue lorsque les prélèvements varient d'un pourcentage, d'un niveau absolu ou sont partiellement harmonisés à un seuil.

DE

Dieser Bericht unterstützt die Überarbeitung der UEBLL und des Abschnitts 7 der AGVO durch die Europäische Kommission. Er besteht aus 3 Studienpunkten, die unterschiedliche Fragen behandeln:

Studienpunkt 1: Die Messung der Kosteneffizienz (EUR pro Tonne CO_2-Vermeidung) ermöglicht die Bewertung der relativen Dekarbonisierungsvorteile von Maßnahmen, erfasst aber möglicherweise nicht immer deren gesamte Umweltauswirkungen. Wind, Solar und Energieeffizienz haben eine ähnliche Kosteneffizienz, während Kraft-Wärme-Kopplung weniger kosteneffizient ist. Wenn man sich nur auf die Ziele der Dekarbonisierung konzentriert, verbessern Multi-Technologie-Auktionen die Kosteneffizienz, indem sie weniger kostspieligen Technologien den Vorrang geben. Wenn potenzielle inframarginale Renten und dynamische Effekte ebenfalls berücksichtigt werden, dann können technologiespezifische Auktionen in einigen Fällen niedrigere Kosten für die CO_2-Reduzierung aufweisen.

Studienpunkt 2: Es wird ein Überblick über die Forschung zu Betriebs- und Investitionsbeihilfen gegeben, mit dem Ergebnis, dass bei Beihilfen für umweltfreundliche Energie zwar einige Verzerrungen durch die Art der Beihilfe entstanden sind, dass aber sowohl Investitions- als auch insbesondere Betriebsbeihilfen zu positiven Ergebnissen führen können. Die Analyse von vier konkreten Maßnahmen mit Betriebs- oder Investitionsbeihilfen legt nahe, dass die genaue Ausgestaltung der Maßnahmen für den Erfolg entscheidend ist und sich oft im Laufe der Zeit weiterentwickelt. Es werden drei Beihilfemaßnahmen für die Dekarbonisierung der Industrie untersucht. Es ist davon auszugehen, dass Beihilfen mit einer festen Höhe von 40 % bei unveränderten Beihilfehöchstintensitäten keine ausreichende Unterstützung für verschiedene Dekarbonisierungsoptionen in der Industrie bieten.

Studienpunkt 3: Empirische Studien stützen die Relevanz von Stromintensität und Handelsintensität für die Auswahl von energieintensiven Unternehmen für Umlagebefreiungen in der UEBLL. Die Analyse der Abgaben von 2011 bis 2018 unterstreicht die große Heterogenität der Umlagen über Branchen, Länder und im Zeitverlauf. Szenarien, in denen die Abgaben auf die höchste Abgabe harmonisiert und Ausnahmen abgeschafft werden, führen zu einem erheblichen Gewinnrückgang. Ein begrenzter Gewinnrückgang ist zu erwarten, wenn die Abgaben um einen prozentualen Wert oder ein absolutes Niveau geändert werden oder teilweise auf einen Schwellenwert harmonisiert werden.

Executive Summary

Introduction and Study Assignment by the Commission

As part of the revision process of the current State aid rules, the Directorate General for competition of the European Commission (DG COMP) has commissioned the consortium consisting of E.CA Economics, DIW Berlin, LEAR, Sheppard Mullin and University of East Anglia (UEA) with an external study to support the Commission in its revision of the EU Guidelines on State aid for environmental protection and energy (EEAG) and the General Block Exemption Regulation (GBER) as related to environmental and energy aid.

This study addresses the following three broad topics ("study items"):

- **Study Item 1: Transparency, tendering and broadening.** The large investments needed for a transition to a low-carbon economy warrant the consideration of a potential revision of the rules that ensures that State aid schemes for environmental protection and industrial decarbonisation are cost-effective (i.e. minimise the costs to achieve environmental benefits) and do not unduly distort competition (i.e. the environmental aid is proportionate and directed to what is needed). Against this background, study item 1 examines whether and how the transparency of environmental protection costs of decarbonisation aid schemes should be increased by quantifying both the benefits to environmental protection and their costs. Further, the study item addresses whether tendering requirements in aid schemes should be extended. Finally, the study item assesses whether environmental protection schemes can be broadened to different sectors and technologies which could advance the same environmental protection objective to a similar extent, rather than being sector- or technology-specific.
- **Study Item 2: Operating vs. investment aid.** In the current EEAG and GBER, the distinction between operating aid and investment aid plays an important role. However, the challenges of the green transition might require new types of aid and the traditional distinction between operating aid and investment aid needs to be re-examined. Hence, study item 2 examines the effectiveness and distortive effect of different forms of aid by reviewing the existing literature, case studies on four representative schemes and modelling hypothetical future aid schemes in important sectors.
- **Study Item 3: Energy-Intensive Users**. The objective of study item 3 is twofold: Firstly, it assesses whether the economic parameters currently used by the EEAG Guidelines 2014 to determine the eligibility of sectors for exemptions from decarbonisation levies for Energy-Intensive Users ("EIUs") are the most relevant parameters for the risk of relocation from an economic perspective. Secondly, it aims at determining the extent to which the profitability of EIUs is affected by different levels of Renewable Energy Sources (RES) and Combined Heat Power (CHP) levies on electricity for a sample of 10 sectors.

The report is structured along the three study items (sections1, 2, and 3, respectively). The Annexes contain information which is complementary to the respective study items, such as lists of literature, additional graphs and results as well as robustness checks.

Main results for Study Item 1: Transparency, tendering and broadening

Increased transparency of environmental aid schemes would facilitate the evaluation of the costs and benefits of the aid. To help the Commission to measure such costs and benefits in a harmonised manner, at least for decarbonisation support, this report provides a review of the available academic research and reports on how to measure the cost-effectiveness of decarbonisation support schemes. The findings may not be applicable to other areas of environmental protection such as circularity and clean mobility. Cost-effectiveness of decarbonisation is generally measured in terms of EUR per tonne of abated CO_2 or CO_2 equivalent emissions (€/tCO_2 or €/tCO_2e). Costs are generally computed as the amount of the support net of monetisable benefits (e.g. fuel costs savings, carbon costs savings and capacity savings). In the papers reviewed, the appraisal of the mitigated

CO_2 emission is limited to the emission reductions in the market directly targeted by the measure and, in case of renewable energy support, in the power sector. It may be relevant, however, to assess the abatement and price interaction effects with overlapping decarbonisation measures, such as the EU Emissions Trading System. When co-existing with an emissions trading regime, decarbonisation policies may lower the CO_2 price while only shifting emissions to other locations ("waterbed effect"). The literature discusses the relevance of such an effect when assessing cost-effectiveness. The academic research also urges the need to take into account spill-overs to other sectors (e.g. industry, heating, transport), behavioural responses, learning-by-doing effects, and the impact on biodiversity and natural ecosystems. The appraisal of learning-by-doing effects would require a long-term perspective: immature technologies may have large potential for cost reduction and as a result be cost-effective in the long run. There may be a trade-off between short- and long-term horizon when assessing cost-effectiveness. On the one hand, policy measures which are cost-effective in the short term may not allow to reach long term emission targets at the lowest possible costs. On the other hand, since investments are irreversible, policymakers face the risks of being locked in an outdated technology which may not become cost-effective even in the long term.

The review shows that Member States are increasingly relying or planning to rely on the €/tCO_2 criterion to allocate the support for renewable energy and decarbonisation schemes or to assess their effectiveness. This suggests that there are benefits in moving away from approaches that select the measures to be aided based on the cost per unit of energy output (€/kWh of energy produced) which ignore any environmental costs and benefits. The cost-effectiveness metric should facilitate a better evaluation of the contribution to the targeted environmental objective and the proportionality of the aid; in addition, it should help identify measures which have an unusually high cost and merit further scrutiny or stricter compatibility conditions. As mentioned above, the review of the literature shows that there are some caveats to bear in mind (e.g. inclusion of positive or negative environmental externalities) and that the metric could be further refined.

The 2014 EEAG introduced a general requirement for competitive bidding procedures to grant aid for electricity generation from renewable energy sources. The rationale that has spurred such introduction is that, by stimulating competition among potential beneficiaries, auctions may enhance technological development, avoid the risk of overcompensation and more generally lead to the minimisation of support costs. Study item 1 reviews under which conditions auctions can be expected to be sufficiently competitive and therefore lead to cost discovery as well as aid proportionality. The literature review is mainly based on – although not limited to – the existing papers on auctions for renewable energy generation. Despite this, the general findings are applicable to any auction scheme. The literature shows that auction design can have an impact on participation, competition, and in turn, bidding behaviour. The main design elements that can influence the outcomes of the auctions are pricing rules (pay-as-bid or uniform price), formats (static, dynamic or hybrid), and scoring rules (based only on price or on multiple factors). Finally, there is a debate on whether auctions should be technology-neutral – i.e. open to all available technologies which would compete under a common budget – or technology-specific. Although technology-neutral auctions can lead to cost minimisation, at least in the short term, they may also lock out the most expensive technologies and generate windfall profits for the least expensive ones. Technology-specific auctions may foster technology diversity and enhance security of supply. Finally, experiences in some Member States point toward the use of auctions to support low carbon technologies other than renewable generation (e.g. energy efficiency measures and combined heat and power plants in Germany). This evidence will be useful for the Commission to assess if and to what extent tendering should be extended to further areas.

To help the Commission evaluate to what extent environmental protection and decarbonisation schemes should be broadened to multiple sectors and technologies, study item 1 relies both on a literature review and a case study analysis.

In the last decade, Member States have been increasingly relying on multi-technology schemes for the support of electricity generation from renewable energy sources and multi-sector schemes for decarbonisation. While technology-neutral schemes support technology deployment without any discrimination across technologies and sectors, multi-technology and multi-sector schemes promote selected and multiple technology fields and sectors. In both cases, multiple technologies and sectors compete under the same budget. The literature review presents the results of such broadened schemes. The main finding is that broadening support schemes to sectors and technologies promoting similar environmental objectives could help minimise the aid amount, and thus, lead to more cost-effective policy. Nonetheless, their implementation may carry some risks. Multi-technology auctions for RES support may risk crowding out innovative technologies and reduce actor diversity. Multi-sector schemes for decarbonisation support require conversion factors to assess the impact on CO_2 emissions, and the price of each technology will be expressed in €/tCO_2 (or CO_2 equivalent) avoided. While there are some advantages over measures that select beneficiaries based on €/kWh, it may be difficult to identify a single methodology that allows to calculate both emission and cost reductions in a fair way across several technologies and sectors. Furthermore, broader tenders across multiple sectors, by enhancing competition between bidders under a single budget, may magnify the risk of underbidding.

The case study analysis is based on support schemes for wind, solar, combined heat and power (CHP) and energy efficiency implemented in Denmark, Germany and Poland. The methodology builds on a conceptual framework assessing how emissions are marginally reduced by the various investigated technologies in current and future power and energy systems, and what support for carbon mitigation will be needed over the coming years.

The backward-looking cost-effectiveness evaluation finds that the overall level of carbon mitigation costs for solar, wind and energy efficiency measures other than CHP is similar. For CHP there are strong within-technology and across-country differences, driven by differences in absolute payment levels and carbon mitigation effects of avoided and produced emissions. While the mitigation costs of support for gas-fired installations in Poland are comparable to that of RES technologies, CHP auctions in Germany and administrative CHP support in Denmark have respectively about two and four times higher mitigation costs than the support for wind and solar installations. Where more polluting technologies are supported – e.g. the oil-fired CHP plants eligible for the German scheme or coal-fired plants eligible for the Polish scheme – these technologies have two to three times higher mitigation costs compared to gas-fired installations. While the results are robust to assumptions of curtailment and market values of technologies, other parameters such as discounting rates and assumed technology displacement mixes can drive results and make comparisons between two sets of cost-effectiveness analysis challenging. However, while there may be other benefits to supporting CHP, CHP plants may be a significantly less cost-effective way to decarbonise than wind, solar and the other energy efficiency measures studied.

While there are difficulties in calculating the cost per tCO_2, and such a measure may not recognise all benefits associated with a particular project, €/tCO_2 could provide a greater indication of the relative decarbonisation benefit of different projects than the more usual measure of €/kW or €/kWh.

A dynamic and static counterfactual simulation analysis comparing technology-specific and multi-technology tenders, based on a harmonised €/tCO_2 criteria across technologies and following the cost-effectiveness evaluation, shows mixed results. For the simulation we assume uniform pricing, perfect competition and information, and ignore dynamic effects, as well as other environmental and system impacts. In Poland and Denmark cost savings of shifting away from more expensive technologies (i.e., CHP) outweigh potential windfall profits from joint clearing prices, and lead to mitigation cost reductions of 6-7%. In the German case cost savings of 6% were computed for one year, whereas in two years multi-technology auctions would have increased costs by 5%. In these instances, the better performance of technology-specific auctions results from intra-technology price discrimination in the case of onshore wind. We assume allocative inefficiencies leading to a selection of wind-poor over wind-rich locations are limited.

The introduction of price (or offer) caps for specific technologies in multi-technology auctions has a limited effect. Price caps improve the performance of the multi-technology auction in the Danish simulation case by avoiding windfall profits for PV and onshore wind in the situation where offshore wind is price setting. This leads to approximately 9% lower mitigation cost as compared to multi-technology auctions without price caps. In Germany, price caps lead to the exclusion of part of the potential of cheaper technologies when set too low.

The extension of the static to a dynamic simulation from 2020 to 2030 allows for an assessment of the role that limited technology potentials and supply chain impacts of varying demand levels could play: whereas in a setting without these effects, multi-technology tenders have slightly lower mitigation costs of around 1%, the inclusion of these effects increases the cost of multi-technology tenders by around 2% so that technology-specific tenders exhibit slightly lower mitigation costs if these effects are considered. This effect increases with tighter renewable potential.

Concluding the counterfactual simulations, we find that a shift from technology-specific to multi-technology auctions can result – in a static setting – in a reduction of mitigation costs by 6% (Denmark and Poland), but may in some years also result in an increase of mitigation costs by 6% in countries where a multi-technology auction would preclude intra-technology price discrimination and where we assume allocative inefficiencies are limited (Germany). Where multi-technology auctions result in high windfall profits for infra-marginal technologies (Denmark), the mitigation costs can be decreased by technology-specific price caps. In cases where bid-caps exclude cost efficient technology potentials (Germany) they can also increase mitigation costs.

If it is considered that sites for wind- and solar-power are overall constrained, then we find in a dynamic simulation cost savings of multi-technology auctions of 1% relative to a technology-specific auction. If, in addition, supply chain impacts from volatile technology demand are considered, then technology-specific tenders exhibit cost savings of 1%.

Main results for Study Item 2: Investment and operating aid

The report also provides the Commission with data, analysis and expert judgements on the effects of awarding State aid either as investment aid or operating aid. This can help the Commission in examining whether this distinction is still justified and therefore whether compatibility rules for investment and operating aid should be aligned.

Evidence is gathered on three main areas:

- Reviewing the existing literature on the effectiveness of the distinction between operating aid and investment aid in the context of the EEAG; the reviewed literature focused strongly on aid in the field of support for environmentally friendly energy production;
- A comparison of operating aid and investment aid across four EEAG and GBER schemes; and
- A set of hypothetical support schemes for industrial decarbonisation, with their impact on three industries: steel, cement and fertilisers (represented by ammonia).

Overall, the literature review showed that, in the field of support for environmentally friendly energy production, operating aid is more frequently shown to be effective at securing investment than investment aid. Part of the literature review seems to suggest that this might in part be due to the fact that the amount of investment aid provided was too low.

Both types of aid contribute to the economic feasibility of the environmental protection measures, however, they do so in different ways, suggesting both may still have an important role within the State aid toolkit.

However, the distinction between operating and investment aid may be less clear with respect to environmental aid than other sectors, as many projects are capital intensive and therefore various combinations of investment and operating aid can motivate such investments. Expectations of operating aid often play into the considerations a company considering investments in energy or industrial infrastructure. Equally, from a purely financial perspective, investment decisions can be influenced by investment aid or operating aid or, in circumstances where both are available, a combination of the two.

In practice, operating aid seems more frequently awarded, while investment aid, under the existing rules (aid capped at certain maximum aid intensities), can fail to cover the increased costs of investment. Solutions have already been found for appropriately incentivising energy investments, with some new energy investments having aid levels bid down to zero, suggesting that State aid for certain categories of energy investment may be increasingly unnecessary as the market alone may accommodate necessary investments due to decreasing investment costs and increasing demand for renewable energy and, potentially, external support for network costs.

We also reviewed literature on the distortive effect of operating aid and investment aid and found that price-based operating aid combined with the low marginal cost of PV, wind and hydro can have a distortive effect on markets, in some cases causing negative prices. Low or negative market prices may harm investor confidence and could lead to subsidy-driven investment decisions which could lock in a subsidy dependant pathway.

Some forms of aid (feed-in tariffs) were found to be more distortive to markets than others (feed-in premiums) as feed-in tariffs completely shield producers from market exposure, and responses to market signals. Therefore, policy makers need to consider the potential distortive effect of aid when designing price-based operating aid instruments.

More extreme solutions such as the departure from price-based payments over time to capacity-based payments over time are also suggested by some researchers.

In order to better understand how energy-related investment and operating aid work for motivating investment and achieving benefits in practice, four schemes are examined in detail to gain a deeper understanding of the impacts of investment and operating aid for different types of technologies. These schemes include a PV energy scheme with investment aid, a biogas scheme with operating and investment aid, a CHP scheme with operating and investment aid and a scheme for high-efficient natural gas cogeneration with operating aid. The solar investment aid scheme is being discontinued due to the level of aid not making private profitability feasible.

Operating aid support for PV in a comparator scheme experienced major fluctuations in investment levels as administratively set operating aid failed to capture the rapidly decreasing investment costs of PV which caused an increase in investment when aid was high, followed by a decrease in investment when support was lowered. Competitively set support levels appear to offer a solution to this problem by offering more accurate cost discovery.

Industrial decarbonisation seems less mature than energy generation decarbonisation. While industrial decarbonisation shares some of the complexities of energy decarbonisation, for instance the existence of various technologies with different costs, it differs from energy to the extent that: (1) some industrial sectors can be much more economically decarbonised than others, (2) the industrial activities studied produce generally distinct end products that are not substitutes to each other, unlike energy outputs that are often substitutes to at least some extent and (3) operating costs do not often fall post–investment, compared to the prior industry technology, unlike with the wind and PV investments that lowered variable costs of energy production compared to the prior fossil fuel technologies.

Comparisons between potential schemes for industrial decarbonisation suggest that investment aid at about 40% of eligible costs (i.e. extra investment costs) is unlikely to achieve substantial incentives for large and expensive investment unless operating costs fall compared to the traditional technology or government-imposed charges on traditional production are raised. Levels much higher than 40% may be necessary to motivate use of this financing mechanism; levels of between 50% or 70% do not seem to be sufficient either. A 100% support could negate the problem if operating costs remain unchanged for the new technologies compared to the prior technology.

A more flexible option would consist in providing support for new projects that takes account of the lifetime relation between investment, operating costs and revenues. This mode of support could incentivise investments in new technology. This mode of support presents however the risk of increasing costs beyond the minimum necessary when granting authorities have asymmetric information compared to companies on the real costs and real aid amount needed, which may inflate costs in aid applications, and when businesses have ongoing reduced incentives from a lack of external efficiency pressures. These two weaknesses would be offset if granting authorities would have a full understanding of efficient cost levels.

Carbon contracts for difference (CCfD) may offer a number of advantages, but also have risks to face. Advantages include creating a stable long-term investor climate by setting a fixed cost of carbon (and value of carbon reduction) for the investor. The percentage of equity required for financing a CCfD can fall compared to investment without a CCfD, ultimately meaning that government financial resources can support a larger total volume of investment. Disadvantages include that a CCfD is nonetheless still subject to government (or government entities) bearing the risk of ETS price variability, market power risks and potential cost increases from a lack of external pressure to be efficient. A particularly important trade-off on decarbonisation of specific industries against efficiency can be observed in the decision that would be made over whether to set prices of CCfD tenders within an industry or across industries. For example, steel and ammonia would have limited incumbent competition in single-industry competitive bidding processes as 20 Member States have 1 or 0 incumbent steel facilities, and 18 Member States have 1 or 0 incumbent ammonia facilities. If CCfD competitive bidding processes run across multiple industries, efficiency will be enhanced, but some industries might be likely to achieve higher decarbonisation than others due to having technologies with lower costs of achieving CO_2 reductions than others.

Main results for Study Item 3: Energy Intensive Users

Based on a literature survey, measures of electro-intensity and trade intensity are found to be relevant for the risk of relocation of firms.

Regarding electro-intensity, empirical studies find that the most energy-intensive firms are negatively affected by increases in energy prices (including levies) on various dimensions: production, productivity, employment, probability of exit, exports and imports. Those studies, at the same time, find no statistically or economically significant effect for an average firm, based on a sample of both energy-intensive and non-energy-intensive firms. The different effects on energy-intensive and non-energy-intensive firms supports the relevance of electro-intensity as an important criterion in the EEAG.

Regarding trade intensity, the literature also confirms its relevance as a criterion to distinguish between sectors of high and low risk of relocation due to changes in levy levels. This result, however, is based on a few studies only. The identified relocation effect is strongest for sectors trading with less developed countries, including China. Those trade partners often have less stringent carbon mitigation rules.

More broadly, the literature suggests that levy exemptions should be targeted towards sectors with a comparative energy cost disadvantage (i.e. which trade with countries where energy costs are lower than in the EU), towards sectors with high capital mobility, and towards sectors trading with countries using protectionist measures. A further proposal from the literature is to apply product-specific efficiency benchmarks for electro-intensity per physical unit of output to incentivise implementation of energy efficient technology and at the same time to restore competitiveness.

Practical implementation of those improvements is, however, difficult. This is due to a lack of reliable and regularly updated data sources, which would allow to measure those criteria across sectors and, thereby, to separate eligible sectors from non-eligible sectors. In this study, we make recommendations on how to alleviate these practical limitations. Yet, some question marks on the feasibility of their implementation remain.

Beyond a critical review of the literature, our study provides a description of the RES and CHP levy data for 10 selected sectors[1] for 11 Member States[2] ("EU-11") in the time period 2011 to 2018. Three other countries also used RES and/or CHP levies to support RES and CHP electricity generation, but could not be analysed due to the lack of disaggregated electricity consumption data (Italy, Romania and Estonia). The remaining EU countries did not collect RES and/or CHP levies. A potentially important limitation of our descriptive analyses is that levies – and exemptions thereof – can only be calculated for a firm with average electricity consumption in a specific country and sector. Our descriptive analysis, therefore, also depicts levies – and exemptions thereof – only for a firm with average electricity consumption in the sector. Within-sector heterogeneity with respect to electro-intensity and its implications for levy levels for individual firms within a sector cannot be analysed. Despite this limitation, we consider our descriptive analyses relevant for understanding across-sector heterogeneity and robust in providing an aggregated view on the question at hand.

Based on this data, we provide relevant statistics for the levels of RES and CHP full levies and exemptions thereof for the time period 2011 to 2018. We come to the following results:

First, regarding individual countries, we find that Germany has the highest and over time increasing *full* levies. The levies vary between 3 to 7 eurocent/kWh during the observation period. In contrast, when deducting levy exemptions from full levies (i.e. focusing on *effective* levies), in several sectors eligible firms in Germany face levies which are in line with other analysed Member States, for which effective levies vary between zero and 1.5 eurocent/kWh. A country with relatively high levies, both full and effective, is Latvia. This is due to significant full CHP levies and no exemptions being available. In Poland, levies are at minimum levels in seven out of ten sectors in 2018. France has no levies since 2016.

Second, focusing on the EU-11 average, EU-11 average full levies (weighted by turnover) increase over the observation period from about 2 to over 4 cent/kWh in seven out of the 10 sectors. This result is mostly driven by a strong increase of levies in Germany, which persistently holds a high share of turnover in the sectors analysed and, hence, substantially influences the EU-11 average full levy over the observation period. Focusing on effective levies, i.e. taking exemptions into account, only minor increases can be observed for the EU-11 average levy. Germany is again an important driver of this observation, given its economic importance in the analysed sectors.

While the descriptive analysis offers some insights on the levy level and levy changes across sectors, countries and time, in the next step we carry out an econometric analysis and simulations to assess the potential impact of levies on firms' profitability. This is done for nine manufacturing sectors, for which the identification of the econometric model is possible.

For this purpose, we introduce within-sector heterogeneity in electricity consumption for different firm size groups. The consumption band from Eurostat indicated by the country/sector's average electricity consumption is assigned to large firms. Mid-sized firms are assigned to the next lower consumption band and small firms to the second lower consumption band. We then estimate the elasticity of profits with respect to electricity prices. This elasticity measures the percentage change in profitability in response to a percentage change in electricity prices, of which RES and CHP levies are part of. Based on these estimates, we simulate counterfactual scenarios for levy changes in 2018.

[1] These sectors include: manufacture of non-wovens and articles made from non-wovens, except apparel (NACE code C13.95), manufacture of veneer sheets and wood-based panels (C16.21), manufacture of pulp (C17.11), manufacture of household and sanitary goods and of toilet requisites (C17.22), manufacture of industrial gases (C20.11), manufacture of other inorganic basic chemicals (C20.13), manufacture of basic iron and steel and of ferro-alloys (C24.10), aluminium production (C24.42), copper production (C24.44), data processing, hosting and related activities (J63.11).

[2] These countries include: Austria, Croatia, Denmark, France, Germany, Greece, Latvia, Lithuania, Poland, Slovakia and Slovenia.

To assess the impact of the levies on profitability, the study contains five sets of scenarios. First, we look at two scenarios where full levies are applied. In one scenario the effective levy in a sector is set at the highest sector-specific, full levy observed in 2018 (which is the levy in Germany). In the other full levy scenario, we do not allow for exemptions, i.e. the full levies are also assumed to be the effective levies in a specific sector and country. Second, we assess a set of scenarios where we consider a percentage effective levy change (increase or decrease) with respect to effective levy levels in the *status quo* (-50%, -20%, -10%, +10%, +20%, +50%, +100%). In the third set of scenarios, we assume an increase in cent/kWh with respect to the effective levies in the *status quo* (+0.5 ct, +1ct, +1.5 ct) in all countries and sectors. In the fourth set of scenarios, we analyse the impact of levy harmonisation. Here, the effective levies – across all countries and sectors – are set equal to four different levy levels: 0.5 ct/kWh, 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh, which is the range of average levies across sectors. In a final, fifth set of scenarios, it is assumed that exemptions are only granted when the full levy exceeds a specific threshold. Three thresholds are selected, 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh. We consider two different levels of exemptions: 75% and 85%. In one variation we also allow exemptions to apply only to the part of the full levy exceeding the threshold.

We show that the first two "full levy" scenarios lead to a very substantial decrease in profits. In the other scenarios, the effects on profit vary across sectors both in terms of average effects and across countries, while the cross-country heterogeneity of the effect on profits varies also within each sector. The variation of the impact on profits is thereby driven by three key forces: i) the level of the effective levies in the *status quo*, ii) the cross-country heterogeneity of the *status quo* effective levies in each specific sector, and iii) the nature of the scenario (whether a percentage or level change). Specifically, the levels of levies in the *status quo* and the cross-country variation of the levies in each sector determine the heterogeneity of the profit effect. Sectors with low levies – and consequently low cross-country heterogeneity – show much smaller profit effects and smaller variation across countries than sectors where only some countries hold high levy levels in the *status quo*. In addition, the variation of the effects on profits across countries is also driven by the nature of the experiment: scenarios that harmonise levies to a certain value generate larger variation in profits than levy changes by a percentage value or by an absolute levy level.

The large heterogeneity of effects of levy changes on profits is confirmed by a static model based on sector-wide electricity cost and profitability data from Eurostat and allowing for cost pass-on at levels suggested by sector studies. This model is evaluated for all ten sectors covered by the study. Also in this model, profitability changes (reductions) are the highest in the scenarios assuming levy harmonisation or a switch from effective levies to unexempted, full levy levels.

Finally, to compare these different scenarios, we assess the trade-offs between three main policy objectives: i) collecting the largest possible budget for RES and CHP to support the European Green Deal, ii) limiting the distortion of competition within the EU existing in the *status quo* due to different effective levy levels across countries and iii) limiting a potential negative impact on profits generated by levy changes, which could trigger relocation of firms outside the EU in the long term. We find that scenarios which set the exemptions conditional on the full levy exceeding a certain threshold are best in resolving the trade-offs between these policy objectives. This option assumes levy exemptions only for countries that exhibit a full levy level above the threshold in the *status quo* and for firms eligible for exemptions in the *status quo*. Such a scenario would allow an increase in budget available and reduce the current heterogeneity in levies – thus, the competition distortions. In addition, according to our estimations, it would be unlikely to cause large profitability reductions in most countries and sectors, limiting the risk of relocation.

Résumé (FR)

Introduction et mission d'étude de la Commission

Dans le cadre du processus de révision des règles actuelles en matière d'aides d'État, la Direction générale de la concurrence de la Commission Européenne (DG COMP) a chargé le consortium composé de E.CA Economics, DIW Berlin, LEAR, Sheppard Mullin et University of East Anglia (UEA) de réaliser une étude externe afin de soutenir la Commission dans sa révision des lignes directrices concernant les aides d'État pour la protection de l'environnement et l'énergie (LDEE) et du règlement général d'exemption par catégorie (RGEC) en ce qui concerne les aides à l'environnement et à l'énergie.

Cette étude aborde les trois grands thèmes suivants ("élément d'étude") :

- **Premier élément d'étude : Transparence, appels d'offres et élargissement.** Les grands investissements nécessaires à la transition vers une économie à faible émission de CO_2 justifient l'examen d'une révision potentielle des règles garantissant que les régimes d'aides d'État en faveur de la protection de l'environnement et de la décarbonisation industrielle présentent un bon rapport coût-efficacité (c'est-à-dire qu'ils minimisent les coûts pour obtenir des avantages environnementaux) et ne faussent pas indûment la concurrence (c'est-à-dire que l'aide environnementale est proportionnée et orientée vers ce qui est nécessaire). Dans ce contexte, le premier élément d'étude analyse si et comment la transparence des coûts de protection de l'environnement des régimes d'aide à la décarbonisation devrait être accrue en quantifiant à la fois les avantages pour la protection de l'environnement et leurs coûts. En outre, le premier élément d'étude examine si les exigences en matière d'appels d'offres dans les régimes d'aides devraient être étendues. Enfin, l'étude évalue si les régimes de protection de l'environnement peuvent être élargis à différents secteurs et technologies qui pourraient faire progresser le même objectif de protection de l'environnement dans une mesure similaire, plutôt que d'être spécifiques à un secteur ou à une technologie.
- Deuxième élément d'étude : Aide au fonctionnement ou à l'investissement. Dans les LDEE et le RGEC actuels, la distinction entre les aides au fonctionnement et les aides à l'investissement joue un rôle important. Cependant, les défis de la transition verte pourraient nécessiter de nouveaux types d'aide et la distinction traditionnelle entre l'aide au fonctionnement et l'aide à l'investissement doit être réexaminée. Par conséquent, le deuxième élément de l'étude examine l'efficacité et l'effet de distorsion des différentes formes d'aide en passant en revue la littérature existante, des études de cas sur quatre régimes représentatifs et en modélisant des régimes d'aide hypothétiques dans des secteurs importants.
- **Troisième élément d'étude : Utilisateurs énergo-intensifs.** L'objectif du point 3 de l'étude est double : Premièrement, il évalue si les paramètres économiques actuellement utilisés par les lignes directrices 2014 pour déterminer l'éligibilité des secteurs aux exonérations des prélèvements de décarbonisation pour les utilisateurs énergo-intensifs (UIE) sont les paramètres les plus pertinents pour le risque de délocalisation d'un point de vue économique. Deuxièmement, il vise à déterminer dans quelle mesure la rentabilité des UIE est affectée par différents niveaux de prélèvements sur l'électricité au titre des sources d'énergie renouvelables (SER) et de la production combinée chaleur-électricité (PCCE) ou cogénération pour un échantillon de 10 secteurs.

Le rapport est structuré selon les trois éléments d'étude (sections 1, 2 et 3, respectivement). Les annexes contiennent des informations complémentaires aux éléments d'étude respectifs, telles que des listes de littérature, des graphiques et des résultats supplémentaires ainsi que des contrôles de fiabilité.

Principaux résultats du premier élément de l'étude : Transparence, appels d'offres et élargissement

Une transparence accrue des régimes d'aide à l'environnement faciliterait l'évaluation des coûts et des avantages de ces aides. Pour aider la Commission à mesurer ces coûts et avantages de manière harmonisée, au moins pour les aides à la décarbonisation, le présent rapport passe en revue les recherches et rapports universitaires disponibles sur la manière de mesurer le rapport coût-efficacité des régimes d'aide à la décarbonisation. Les conclusions peuvent ne pas être applicables à d'autres domaines de la protection de l'environnement tels que la circularité et la mobilité écologique. Le rapport coût-efficacité de la décarbonisation est généralement mesuré en termes d'euros par tonne d'émissions réduites de CO_2 ou d'équivalent de CO_2 (€/tCO_2 ou €/tCO_2e). Les coûts sont généralement calculés comme le montant de l'aide net des avantages monétisables (par exemple, les économies de carburant, les économies de carbone et les économies de capacité). Dans les documents examinés, l'évaluation de l'atténuation des émissions de CO_2 se limite aux réductions d'émissions sur le marché directement visé par la mesure et, dans le cas du soutien aux énergies renouvelables, dans le secteur de l'électricité. Il peut toutefois s'avérer pertinent d'évaluer les effets de réduction et d'interaction des prix avec des mesures de décarbonisation qui se chevauchent, telles que le système communautaire d'échange de quotas d'émission. Lorsqu'elles coexistent avec un régime d'échange de quotas d'émission, les politiques de décarbonisation peuvent faire baisser le prix du CO_2 tout en ne faisant que déplacer les émissions vers d'autres lieux (« effet de vases communicants »). La littérature discute de la pertinence d'un tel effet lors de l'évaluation du rapport coût-efficacité. La recherche universitaire insiste également sur la nécessité de prendre en compte les retombées sur d'autres secteurs (par exemple, l'industrie, le chauffage, les transports), les réactions comportementales, les effets d'apprentissage par la pratique et l'impact sur la biodiversité et les écosystèmes naturels. L'évaluation des effets d'apprentissage par la pratique nécessiterait une perspective à long terme : les technologies immatures peuvent avoir un grand potentiel de réduction des coûts et, par conséquent, être rentables à long terme. Il peut y avoir un compromis entre l'horizon à court et à long terme lors de l'évaluation de la rentabilité. D'une part, les mesures politiques qui sont rentables à court terme peuvent ne pas permettre d'atteindre les objectifs d'émission à long terme aux coûts les plus bas possibles. D'autre part, les investissements étant irréversibles, les décideurs risquent de s'enfermer dans une technologie dépassée qui pourrait ne pas être rentable à long terme.

L'examen montre que les États membres s'appuient ou prévoient de s'appuyer de plus en plus sur le critère €/tCO_2 pour attribuer l'aide aux énergies renouvelables et aux programmes de décarbonisation ou pour évaluer leur efficacité. On peut en déduire qu'il est avantageux de s'écarter des approches qui sélectionnent les mesures à aider sur la base du coût par unité d'énergie produite (€/kWh d'énergie produite) et qui ignorent les coûts et avantages environnementaux. La mesure du rapport coût-efficacité devrait faciliter une meilleure évaluation de la contribution à l'objectif environnemental visé et de la proportionnalité de l'aide ; en outre, elle devrait permettre d'identifier les mesures dont le coût est anormalement élevé et qui méritent un examen plus approfondi ou des conditions de compatibilité plus strictes. Comme mentionné ci-dessus, l'examen de la littérature montre qu'il faut tenir compte de certaines réserves (par exemple, l'inclusion des externalités environnementales positives ou négatives) et que la mesure pourrait être affinée.

Les lignes directrices de 2014 ont introduit une exigence générale de procédures d'appel d'offres pour l'octroi d'aides à la production d'électricité à partir de sources d'énergie renouvelables. Le raisonnement qui a suscité cette introduction est que, en stimulant la concurrence entre les bénéficiaires potentiels, les enchères peuvent renforcer le développement technologique, éviter le risque de surcompensation et plus généralement conduire à la minimisation des coûts de soutien. Le premier élément de l'étude examine dans quelles conditions on peut s'attendre à ce que les enchères soient suffisamment compétitives et conduisent donc à la découverte des coûts ainsi qu'à la proportionnalité de l'aide. La revue de la littérature est principalement basée sur - mais pas limitée à - des articles existants sur les ventes aux enchères pour la production d'énergie renouvelable. Malgré cela, les conclusions générales sont applicables à tout système d'enchères. La littérature montre que la conception des enchères peut avoir un impact sur la participation, la concurrence et, par conséquent, sur le comportement des soumissionnaires. Les principaux éléments de conception qui peuvent influencer les résultats des enchères sont les règles de tarification (paiement à l'offre ou prix uniforme), les formats (statique, dynamique ou hybride) et les règles de notation (basées uniquement sur le prix ou sur plusieurs facteurs). Enfin, il existe un débat sur la question de savoir si les enchères doivent être neutres sur le plan technologique - c'est-à-dire ouvertes à toutes les technologies disponibles qui seraient en concurrence dans le cadre d'un budget commun - ou spécifiques sur le plan technologique. Bien que les enchères neutres sur le plan technologique puissent conduire à une minimisation des coûts, du moins à court terme, elles peuvent également exclure les technologies les plus coûteuses et générer des bénéfices exceptionnels pour les moins coûteuses. Les enchères spécifiques à une technologie peuvent favoriser la diversité technologique et renforcer la sécurité d'approvisionnement. Enfin, l'expérience de certains États membres montre qu'il est possible d'utiliser les enchères pour soutenir les technologies à faible émission de CO_2 autres que la production d'énergie renouvelable (par exemple, les mesures d'efficacité énergétique et les centrales de production combinée de chaleur et d'électricité en Allemagne). Ces éléments seront utiles à la Commission pour évaluer si et dans quelle mesure les enchères doivent être étendues à d'autres domaines.

Pour aider la Commission à évaluer dans quelle mesure les régimes de protection de l'environnement et de décarbonisation devraient être étendus à de multiples secteurs et technologies, le premier point de l'étude s'appuie à la fois sur une analyse de la doctrine et sur une analyse d'études de cas.

Au cours de la dernière décennie, les États membres ont eu de plus en plus recours à des régimes multi-technologiques pour soutenir la production d'électricité à partir de sources d'énergie renouvelables et à des régimes multi-sectoriels pour la décarbonisation. Alors que les régimes neutres sur le plan technologique soutiennent le déploiement des technologies sans aucune discrimination entre les technologies et les secteurs, les régimes multi-technologiques et multi-sectoriels favorisent des domaines et des secteurs technologiques sélectionnés et multiples. Dans les deux cas, plusieurs technologies et secteurs sont en concurrence pour le même budget. L'analyse de la doctrine présente les résultats de ces régimes élargis. La principale conclusion est que l'élargissement des régimes de soutien à des secteurs et des technologies promouvant des objectifs environnementaux similaires pourrait contribuer à minimiser le montant de l'aide, et donc à mener une politique plus rentable. Néanmoins, leur mise en œuvre peut comporter certains risques. Les ventes aux enchères multi-technologiques pour le soutien aux SER risquent d'évincer les technologies innovantes et de réduire la diversité des acteurs. Les régimes multi-sectoriels de soutien à la décarbonisation nécessitent des facteurs de conversion pour évaluer l'impact sur les émissions de CO_2, et le prix de chaque technologie sera exprimé en €/tCO_2 (ou équivalent CO_2) évité. Bien qu'il y ait certains avantages par rapport aux mesures qui sélectionnent les bénéficiaires sur la base de €/kWh, il peut être difficile d'identifier une méthodologie unique qui permette de calculer à la fois les réductions d'émissions et de coûts de manière équitable pour plusieurs technologies et secteurs. En outre, des appels d'offres plus larges couvrant plusieurs secteurs, en renforçant la concurrence entre les soumissionnaires dans le cadre d'un budget unique, peuvent amplifier le risque de sous-enchère.

L'analyse de l'étude de cas est basée sur les régimes de soutien à l'énergie éolienne, solaire, à la PCCE et à l'efficacité énergétique mis en œuvre au Danemark, en Allemagne et en Pologne. La méthodologie s'appuie sur un cadre conceptuel évaluant comment les émissions sont marginalement réduites par les différentes technologies étudiées dans les systèmes électriques et énergétiques actuels et futurs, et quel soutien pour la réduction du CO_2 sera nécessaire dans les années à venir.

L'évaluation rétrospective du rapport coût-efficacité montre que le niveau général des coûts d'atténuation des émissions de carbone est similaire pour l'énergie solaire, l'énergie éolienne et les mesures d'efficacité énergétique autres que la cogénération. Pour la PCCE, il existe de fortes différences au sein d'une même technologie et d'un pays à l'autre, en raison des différences entre les niveaux de paiement absolus et les effets d'atténuation du carbone des émissions évitées et produites. Alors que les coûts d'atténuation de l'aide aux installations au gaz en Pologne sont comparables à ceux des technologies SER, les enchères de la cogénération en Allemagne ont des coûts d'atténuation environ deux fois et l'aide administrative à la cogénération au Danemark environ quatre fois plus élevés que l'aide aux installations éoliennes et solaires. Lorsque des technologies plus polluantes sont soutenues - par exemple les centrales de cogénération au mazout admissibles au régime allemand ou les centrales au charbon éligibles au régime polonais - ces technologies ont des coûts d'atténuation deux à trois fois plus élevés que les installations au gaz. Bien que les résultats soient robustes par rapport aux hypothèses de réduction et aux valeurs de marché des technologies, d'autres paramètres tels que les taux d'actualisation et les mélanges de technologies de remplacement supposés peuvent influencer les résultats et rendre difficiles les comparaisons entre deux ensembles d'analyses coût-efficacité. Cependant, bien qu'il puisse y avoir d'autres avantages à soutenir la cogénération, les centrales de cogénération peuvent être un moyen nettement moins rentable de décarboniser que l'éolien, le solaire et les autres mesures d'efficacité énergétique étudiées.

Bien qu'il soit difficile de calculer le coût par tCO_2, et qu'une telle mesure puisse ne pas reconnaître tous les avantages associés à un projet particulier, €/tCO_2 pourrait fournir une meilleure indication de l'avantage relatif de décarbonisation de différents projets que la mesure plus habituelle de €/kW ou €/kWh.

Une analyse de simulation contrefactuelle dynamique et statique comparant des appels d'offres spécifiques à une technologie et des appels d'offres multi-technologiques, sur la base d'un critère €/tCO_2 harmonisé pour toutes les technologies et suivant l'évaluation du rapport coût-efficacité, donne des résultats mitigés. Pour la simulation, nous partons de l'hypothèse d'une tarification uniforme, d'une concurrence et d'une information parfaites, et nous ignorons les effets dynamiques, ainsi que les autres incidences sur l'environnement et le système. En Pologne et au Danemark, les économies réalisées en abandonnant les technologies les plus coûteuses (c'est-à-dire la cogénération) l'emportent sur les bénéfices exceptionnels potentiels des prix de compensation communs et entraînent une réduction des coûts d'atténuation de 6 à 7 %. Dans le cas de l'Allemagne, des économies de 6 % ont été calculées pour une année, alors qu'en deux ans, les enchères multi-technologies auraient augmenté les coûts de 5 %. Dans ces cas, la meilleure performance des enchères spécifiques à une technologie résulte de la discrimination des prix intra-technologie dans le cas de l'éolien terrestre. Nous supposons que les inefficacités d'allocation conduisant à une sélection des sites pauvres en vent par rapport aux sites riches en vent sont limitées.

L'introduction de plafonds de prix (ou d'offres) pour des technologies spécifiques dans les enchères multi-technologiques a un effet limité. Les plafonds de prix améliorent les performances des enchères multi-technologiques dans le cas de simulation danois en évitant les bénéfices exceptionnels pour le photovoltaïque et l'éolien terrestre dans la situation où l'éolien terrestre fixe les prix. Cela conduit à un coût d'atténuation inférieur d'environ 9 % par rapport aux enchères multi-technologiques sans plafonnement des prix. En Allemagne, les plafonds de prix, lorsqu'ils sont fixés trop bas, conduisent à l'exclusion d'une partie du potentiel des technologies moins chères.

L'extension de la simulation statique à une simulation dynamique de 2020 à 2030 permet d'évaluer le rôle que pourraient jouer les potentiels technologiques limités et les incidences sur la chaîne d'approvisionnement des niveaux de demande variables : alors que dans un cadre sans ces effets, les appels d'offres multi-technologiques ont des coûts d'atténuation légèrement inférieurs d'environ 1 %, l'inclusion de ces effets augmente le coût des appels d'offres multi-technologiques d'environ 2 %, de sorte que les appels d'offres spécifiques à une technologie présentent des coûts d'atténuation légèrement inférieurs si ces effets sont pris en compte. Cet effet augmente avec le resserrement du potentiel renouvelable.

En concluant les simulations contrefactuelles, nous constatons que le passage d'enchères spécifiques à une technologie à des enchères multi-technologiques peut entraîner - dans un cadre statique - une réduction des coûts d'atténuation de 6 % (Danemark et Pologne), mais peut également, certaines années, entraîner une augmentation des coûts d'atténuation de 6 % dans les pays où une enchère multi-technologique empêcherait la discrimination des prix intra-technologique et où nous supposons que les inefficacités d'allocation sont limitées (Allemagne). Lorsque les enchères multi-technologiques entraînent des bénéfices exceptionnels élevés pour les technologies infra-marginales (Danemark), les coûts d'atténuation peuvent être réduits par des plafonds de prix spécifiques à la technologie. Dans les cas où les plafonds de prix excluent les potentiels technologiques rentables (Allemagne), ils peuvent également augmenter les coûts d'atténuation.

Si l'on considère que les sites pour l'énergie éolienne et l'énergie solaire sont globalement limités, nous constatons dans une simulation dynamique que les enchères multi-technologies permettent de réduire les coûts de 1% par rapport à une enchère spécifique à une technologie. Si, en outre, les impacts de la chaîne d'approvisionnement dus à la volatilité de la demande de technologie sont pris en compte, alors les enchères spécifiques à une technologie présentent des économies de coûts de 1%.

Principaux résultats du deuxième élément de l'étude : aides à l'investissement et au fonctionnement

Le rapport fournit par ailleurs à la Commission des données, des analyses et des avis d'experts sur les effets de l'octroi d'aides d'État sous forme d'aides à l'investissement ou d'aides au fonctionnement. Cela peut aider la Commission à examiner si cette distinction est toujours justifiée et, par conséquent, si les conditions de compatibilité pour les aides à l'investissement et au fonctionnement devraient être alignées.

Les éléments probants sont recueillis dans trois domaines principaux :

- L'examen de la littérature existante sur l'efficacité de la distinction entre les aides au fonctionnement et les aides à l'investissement dans le contexte des lignes directrices concernant les aides d'État à la protection de l'environnement et à l'énergie; la littérature examinée s'est fortement concentrée sur les aides dans le domaine du soutien à la production d'énergie respectueuse de l'environnement ;
- une comparaison entre les aides au fonctionnement et les aides à l'investissement dans quatre régimes d'aides adoptés sous les LDEE et le RGEC; et
- une série de régimes d'aide hypothétiques en faveur de la décarbonisation industrielle, avec leur impact sur trois industries : l'acier, le ciment et les engrais (représentés par l'ammoniac).

Dans son ensemble, l'analyse de la littérature a montré que, en matière de soutien à la production d'énergie respectueuse de l'environnement, les aides au fonctionnement s'avèrent plus souvent efficaces que les aides à l'investissement pour garantir les investissements. Une partie de l'analyse documentaire semble indiquer que cela pourrait être dû en partie au fait que le montant des aides à l'investissement fournies était trop faible.

Les deux types d'aide contribuent à la faisabilité économique des mesures de protection de l'environnement, mais ils le font de manière différente, ce qui suggère qu'ils peuvent encore jouer un rôle important dans la panoplie des règles d'aides d'État.

Toutefois, la distinction entre les aides au fonctionnement et les aides à l'investissement peut être moins claire en ce qui concerne les aides à l'environnement que dans d'autres secteurs, car de nombreux projets sont à forte intensité de capital et, par conséquent, diverses combinaisons d'aides à l'investissement et au fonctionnement peuvent motiver ces investissements. Les attentes en matière d'aides au fonctionnement entrent souvent en ligne de compte dans les réflexions d'une entreprise qui envisage d'investir dans des infrastructures énergétiques ou industrielles. De même, d'un point de vue purement financier, les décisions d'investissement peuvent être influencées par les aides à l'investissement ou les aides au fonctionnement ou, quand cela est possible, par une combinaison des deux.

Dans la pratique, les aides au fonctionnement semblent plus fréquemment accordées, tandis que les aides à l'investissement, dans le cadre des règles existantes (aides plafonnées à certaines intensités d'aide maximales), ne parviennent pas à couvrir les coûts croissants de l'investissement. Des solutions ont déjà été trouvées pour inciter de manière appropriée les investissements dans le secteur de l'énergie, certains nouveaux investissements dans ce secteur ayant des niveaux d'aide ramenés à zéro, ce qui laisse penser que les aides d'État pour certaines catégories d'investissements dans le secteur de l'énergie pourraient être de moins en moins nécessaires, le marché pouvant à lui seul prendre en charge les investissements nécessaires en raison de la baisse des coûts d'investissement et de l'augmentation de la demande d'énergies renouvelables et, éventuellement, d'un soutien externe pour les coûts de réseau.

Nous avons également examiné la littérature sur l'effet de distorsion des aides au fonctionnement et des aides à l'investissement et nous avons constaté que les aides au fonctionnement basées sur les prix, combinées au faible coût marginal du photovoltaïque, de l'éolien et de l'hydroélectrique peuvent avoir un effet de distorsion sur les marchés, entraînant dans certains cas des prix négatifs. Des prix de marché faibles ou négatifs peuvent nuire à la confiance des investisseurs et conduire à des décisions d'investissements axées sur les subventions, ce qui pourrait les bloquer sur une voie de dépendance aux subventions.

Il s'est avéré que certaines formes d'aide (tarifs de rachat) faussaient davantage les marchés que d'autres (primes de rachat), car les tarifs de rachat protègent complètement les producteurs de l'exposition aux marchés et des réactions aux signaux du marché. Par conséquent, les décideurs politiques doivent tenir compte de l'effet de distorsion potentiel de l'aide lorsqu'ils conçoivent des instruments d'aide au fonctionnement basés sur les prix.

Des solutions plus extrêmes, telles que le passage de paiements fondés sur les prix à des paiements fondés sur la capacité dans le temps, sont également suggérées par certains chercheurs.

Afin de mieux comprendre comment les aides à l'investissement et au fonctionnement liées à l'énergie permettent de motiver les investissements et d'obtenir des avantages dans la pratique, quatre régimes sont examinés en détail pour analyser l'impact des aides à l'investissement et au fonctionnement pour différents types de technologies. Il s'agit d'un régime d'énergie photovoltaïque avec aide à l'investissement, d'un régime de biogaz avec aide au fonctionnement et à l'investissement, d'un régime pour la cogénération avec aide au fonctionnement et à l'investissement, et d'un régime pour la cogénération à haut rendement au gaz naturel avec aide au fonctionnement. Le régime d'aide à l'investissement dans le domaine de l'énergie solaire est en cours d'abandon, le niveau de l'aide ne permettant pas une rentabilité pour les investissements privés.

L'aide au fonctionnement pour le photovoltaïque dans le régime de référence a entraîné d'importantes fluctuations dans les niveaux d'investissement, car l'aide au fonctionnement fixée par l'administration n'a pas permis de tenir compte de la diminution rapide des coûts d'investissement du photovoltaïque, ce qui a entraîné une augmentation des investissements lorsque l'aide était élevée, suivie d'une diminution des investissements lorsque l'aide était réduite. Les niveaux d'aide fixés de manière concurrentielle semblent offrir une solution à ce problème en permettant une analyse plus précise des coûts.

La décarbonisation des industries semble moins développée que dans le domaine de la production d'énergie. Si la décarbonisation industrielle partage certaines des complexités de la décarbonisation de l'énergie, par exemple l'existence de technologies diverses aux coûts différents, elle diffère de celle de l'énergie dans la mesure où : (1) certains secteurs industriels peuvent être décarbonés beaucoup plus économiquement que d'autres, (2) les activités industrielles étudiées produisent des produits finaux distincts qui ne sont pas des substituts les uns des autres, contrairement aux produits énergétiques qui sont des substituts, dans une certaine mesure au moins, et (3) les coûts d'exploitation ne diminuent généralement pas après l'investissement par rapport à la technologie industrielle antérieure, contrairement aux investissements dans l'éolien et le photovoltaïque qui ont fait baisser les coûts variables de la production d'énergie par rapport aux technologies antérieures, contrairement aux investissements dans l'éolien et le photovoltaïque qui ont fait baisser les coûts variables de la production d'énergie par rapport aux technologies antérieures des combustibles fossiles.

Les comparaisons entre les régimes potentiels de décarbonisation industrielle suggèrent que des aides à l'investissement à un niveau de 40 % (des coûts supplémentaires de l'investissement) sont peu susceptibles d'inciter de manière substantielle à des investissements importants et coûteux, à moins que les coûts d'exploitation ne baissent par rapport à la technologie traditionnelle ou que les charges imposées par les pouvoirs publics sur la production traditionnelle ne soient augmentés. Des niveaux bien supérieurs à 40% peuvent se rendre nécessaires pour motiver l'utilisation de ce mécanisme de financement, car le problème semble demeurer à des niveaux entre 50% ou 70%. Un soutien à 100%

pourrait résoudre le problème si les coûts d'exploitation restent inchangés pour les nouvelles technologies par rapport à la technologie antérieure.

Une option plus souple consisterait à fournir un soutien aux nouveaux projets qui tienne en compte de la relation entre l'investissement, les coûts d'exploitation et les revenus sur toute la durée de vie. Ce mode d'aide pourrait encourager les investissements dans les nouvelles technologies. Ce mode de soutien présente toutefois les risque de coûts supérieurs au minimum lorsque les autorités chargées de l'octroi des aides disposent d'informations asymétriques par rapport aux entreprises sur les coûts réels et le montant réel de l'aide nécessaire, ce qui peut gonfler les coûts dans les demandes d'aide, et lorsque les entreprises ont en permanence des incitations réduites en raison d'un manque de pressions externes en matière d'efficacité. Ces deux faiblesses seraient compensées si les autorités chargées de l'octroi des aides avaient une compréhension complète des niveaux de coûts efficaces.

Les contrats de différence liés au carbone (CCFD en anglais) peuvent offrir un certain nombre d'avantages, mais comportent également des risques. Les avantages comprennent la création d'un climat stable pour les investisseurs à long terme en établissant un coût fixe du CO_2 (et la valeur de sa réduction) pour les investisseurs. Le pourcentage de fonds propres requis pour le financement d'un CCFD peut diminuer fortement par rapport à un investissement sans CCFD, ce qui signifie en fin de compte que les ressources financières publiques peuvent soutenir un volume total d'investissement plus important. Parmi les inconvénients, citons le fait qu'un CCFD implique néanmoins que les pouvoirs publics (ou des entités publiques) supportent le risque de variabilité des prix du système d'échange de quotas d'émission de l'UE, les risques liés au pouvoir de marché et les augmentations potentielles de coûts dues à un manque de pression extérieur pour être efficace. Un compromis particulièrement important entre la décarbonisation d'industries spécifiques et l'efficacité peut être observé dans la décision qui serait prise entre fixer les prix des appels d'offres des CCFD au sein d'une industrie ou entre les industries. Par exemple, les secteurs de l'acier et de l'ammoniac ne connaîtraient qu'une concurrence limitée dans le cadre d'appels d'offres mono-industries, étant donné que 20 États membres ne comptent qu'une seule ou aucune installation sidérurgique et que 18 États membres ne comptent qu'une seule ou aucune installation d'ammoniac actuellement présente sur le marché. Si les processus d'appel d'offres concurrentiels du CCFD s'appliquent à plusieurs industries, l'efficacité sera améliorée, mais certaines industries parviendront probablement à une décarbonisation plus importante que d'autres, car elles disposent de technologies dont les coûts de réduction des émissions de CO_2 sont moins élevés que d'autres.

Principaux résultats du troisième élément de l'étude : Utilisateurs énergo-intensifs

Sur la base d'une enquête littéraire, les mesures de l'électro-intensité et de l'intensité commerciale s'avèrent pertinentes pour évaluer le risque de délocalisation des entreprises.

En ce qui concerne l'électro-intensité, les études empiriques montrent que les entreprises les plus énergo-intensives sont affectées négativement par les augmentations des prix de l'énergie (y compris les prélèvements) sur plusieurs plans : production, productivité, emploi, probabilité de sortie, exportations et importations. En même temps, ces études ne constatent aucun effet statistiquement ou économiquement significatif pour une entreprise moyenne, sur la base d'un échantillon comprenant des entreprises à faible ainsi qu'à forte intensité énergétique. Les effets différents sur les entreprises à forte et à faible intensité énergétique confirment la pertinence de l'électro-intensité en tant que critère important dans les LDEE.

En ce qui concerne l'intensité commerciale, la littérature confirme également sa pertinence en tant que critère permettant de distinguer les secteurs présentant un risque élevé et faible de délocalisation en raison de modifications des niveaux de prélèvement. Ce résultat ne repose toutefois que sur quelques études. L'effet de délocalisation identifié est le plus fort pour les secteurs commerçant avec des pays moins développés, dont la Chine. Ces partenaires commerciaux ont souvent des règles de réduction du CO_2 moins strictes.

Plus généralement, la littérature suggère que les exonérations de prélèvements devraient être ciblées sur les secteurs présentant un désavantage comparatif en matière de coûts énergétiques (c'est-à-dire qui commercent avec des pays où les coûts énergétiques sont inférieurs à ceux de l'UE), sur les secteurs à forte mobilité des capitaux et sur les secteurs qui commercent avec des pays utilisant des mesures protectionnistes. Une autre proposition issue de la littérature consiste à appliquer des critères d'efficacité spécifiques aux produits pour l'électro-intensité par unité physique de production afin d'encourager la mise en œuvre de technologies efficaces sur le plan énergétique et, dans le même temps, de rétablir la compétitivité.

La mise en œuvre pratique de ces améliorations est toutefois difficile. Ceci est dû au manque de sources de données fiables et régulièrement mises à jour, qui permettraient de mesurer ces critères dans les différents secteurs et, ainsi, de séparer les secteurs admissibles des secteurs non admissibles. Dans cette étude, nous formulons des recommandations sur la manière de pallier ces difficultés pratiques. Cependant, certains points d'interrogation subsistent quant à la faisabilité de leur mise en œuvre.

Au-delà d'un examen critique de la littérature, notre étude fournit une description des données relatives aux prélèvements sur les SER et la cogénération pour 10 secteurs sélectionnés[3] dans 11 États membres[4] ("UE-11"). Trois autres pays prélèvent également sur les SER et/ou la PCCE pour soutenir la production d'électricité à partir de SER et de PCCE, mais n'ont pas pu être analysés en raison de l'absence de données désagrégées sur la consommation d'électricité (Italie, Roumanie et Estonie). Les autres pays de l'UE ne prélèvent pas sur les SER et/ou la cogénération. Une limitation potentiellement importante de nos analyses descriptives est que les prélèvements - et leurs exonérations - ne peuvent être calculés que pour une entreprise ayant une consommation d'électricité moyenne dans un pays et un secteur spécifique. Notre analyse descriptive décrit donc également les prélèvements - et leurs exonérations - uniquement pour une entreprise ayant une consommation d'électricité moyenne dans le secteur. L'hétérogénéité au sein d'un secteur en ce qui concerne l'électro-intensité et ses implications sur les niveaux de prélèvement pour les entreprises individuelles au sein d'un secteur ne peut être analysée. Malgré cette limitation, nous considérons que nos analyses descriptives sont pertinentes pour comprendre l'hétérogénéité intersectorielle et qu'elles sont solides pour fournir une vue agrégée de la question à l'étude.

Sur la base de ces données, nous fournissons des statistiques pertinentes pour les niveaux de prélèvements complets sur les énergies renouvelables et la cogénération et leurs exemptions pour la période 2011 à 2018. Nous arrivons aux résultats suivants :

Tout d'abord, en ce qui concerne les pays individuels, nous constatons que l'Allemagne a les prélèvements complets les plus élevés et qui augmentent avec le temps. Ces prélèvements varient entre 3 et 7 centimes d'euro/kWh au cours de la période d'observation. En revanche, si l'on déduit les exonérations des prélèvements complets (c'est-à-dire si l'on se concentre sur les prélèvements effectifs), dans plusieurs secteurs, les entreprises éligibles en Allemagne sont soumises à des prélèvements qui sont conformes à ceux des autres États membres analysés, pour lesquels les prélèvements effectifs varient entre zéro et 1,5 centimes/kWh. La Lettonie est un pays où les prélèvements, tant totaux qu'effectifs, sont relativement élevés. Cela est dû à des prélèvements complets importants sur la cogénération et à l'absence d'exemptions. En Pologne, les prélèvements sont à des niveaux minimums dans sept secteurs sur dix en 2018. La France n'applique pas de prélèvements depuis 2016.

Deuxièmement, en se concentrant sur la moyenne de l'UE-11, les prélèvements complets moyens de l'UE-11 (pondérés par le chiffre d'affaires) augmentent au cours de la période

[3] Ces pays sont les suivants : Allemagne, Autriche, Croatie, Danemark, France, Grèce, Lettonie, Lituanie, Pologne, Slovaquie et Slovénie.

[4] Ces secteurs comprennent : la fabrication de non-tissés et d'articles en non-tissés, à l'exception des vêtements (code NACE C13.95), la fabrication de feuilles de placage et de panneaux à base de bois (C16.21), la fabrication de pâte à papier (C17.11), la fabrication d'articles ménagers et sanitaires et d'articles de toilette (C17.22), la fabrication de gaz industriels (C20.11), la fabrication d'autres produits chimiques inorganiques de base (C20.13), la fabrication de fer et d'acier de base et de ferro-alliages (C24.10), la production d'aluminium (C24.42), la production de cuivre (C24.44), le traitement des données, l'hébergement et les activités connexes (J63.11).

d'observation d'environ 2 à plus de 4 centimes/kWh dans sept des dix secteurs. Ce résultat est principalement dû à une forte augmentation des prélèvements en Allemagne, qui détient toujours une part élevée du chiffre d'affaires dans les secteurs analysés et qui, par conséquent, influence considérablement le prélèvement complet moyen de l'UE-11 sur la période d'observation. Si l'on se concentre sur les prélèvements effectifs, c'est-à-dire en tenant compte des exonérations, on ne constate que des augmentations mineures du prélèvement moyen dans l'UE-11. Une fois encore, l'Allemagne est un facteur important de cette observation, étant donné son importance économique dans les secteurs analysés.

Alors que l'analyse descriptive offre un aperçu du niveau des prélèvements et de leur évolution dans les secteurs, les pays et le temps, nous effectuons dans l'étape suivante une analyse économétrique et des simulations pour évaluer l'impact potentiel des prélèvements sur la rentabilité des entreprises.

À cette fin, nous introduisons une hétérogénéité intra-sectorielle dans la consommation d'électricité pour différents groupes de taille d'entreprise. La tranche de consommation d'Eurostat indiquée pour la consommation moyenne d'électricité du pays/secteur est attribuée aux grandes entreprises, les entreprises de taille moyenne à la tranche de consommation immédiatement inférieure et les petites entreprises à la deuxième tranche de consommation inférieure. Nous estimons ainsi l'élasticité des bénéfices par rapport aux prix de l'électricité. Cette élasticité mesure la variation en pourcentage de la rentabilité en réponse à une variation en pourcentage des prix de l'électricité, dont font partie les prélèvements sur les SER et la cogénération. Sur la base de ces estimations, nous simulons des scénarios contrefactuels pour les changements de prélèvements en 2018.

Pour évaluer l'impact des prélèvements sur la rentabilité, l'étude contient cinq séries de scénarios. Tout d'abord, nous examinons deux scénarios dans lesquels les prélèvements complets sont appliqués. Dans un scénario, le prélèvement effectif dans un secteur est fixé au prélèvement intégral sectoriel le plus élevé observé en 2018 (qui est le prélèvement en Allemagne). Dans l'autre scénario de prélèvement intégral, nous ne permettons pas d'exemptions, c'est-à-dire que les prélèvements intégraux sont également supposés être les prélèvements effectifs dans un secteur et un pays spécifiques. Deuxièmement, nous évaluons une série de scénarios dans lesquels nous considérons un pourcentage de changement de prélèvement effectif (augmentation ou diminution) par rapport aux niveaux de prélèvement effectif dans le statu quo (-50%, -20%, -10%, +10%, +20%, +50%, +100%). Dans la troisième série de scénarios, nous supposons une augmentation en cents/kWh par rapport aux prélèvements effectifs du statu quo (+0,5 ct, +1ct, +1,5 ct) dans tous les pays et secteurs. Dans la quatrième série de scénarios, nous analysons l'impact de l'harmonisation des prélèvements. Ici, les prélèvements effectifs - dans tous les pays et secteurs - sont fixés à quatre niveaux de prélèvement différents : 0,5 ct/kWh, 1 ct/kWh, 1,5 ct/kWh et 2 ct/kWh, ce qui correspond à la fourchette des prélèvements moyens dans les secteurs. Dans une dernière et cinquième série de scénarios, on suppose que les exemptions ne sont accordées que lorsque le prélèvement total dépasse un seuil spécifique. Trois seuils sont retenus, 1 ct/kWh, 1,5 ct/kWh et 2 ct/kWh. Nous considérons deux niveaux différents d'exemptions : 75 % et 85 %. Dans une variante, nous permettons également que les exemptions ne s'appliquent qu'à la partie de la redevance totale dépassant le seuil.

Nous montrons que les deux premiers scénarios de "prélèvement intégral" entraînent une baisse très importante des bénéfices. Dans les autres scénarios, les effets sur les bénéfices varient entre les secteurs, tant en termes d'effets moyens qu'entre les pays, tandis que l'hétérogénéité entre les pays de l'effet sur les bénéfices varie également au sein de chaque secteur. La variation de l'impact sur les bénéfices est donc déterminée par trois forces principales : i) le niveau des prélèvements effectifs dans le statu quo, ii) l'hétérogénéité entre pays des prélèvements effectifs dans chaque secteur spécifique, et iii) la nature de l'expérience politique (changement de pourcentage ou de niveau). Plus précisément, les niveaux de prélèvements dans le statu quo et la variation entre pays des prélèvements dans chaque secteur déterminent l'hétérogénéité de l'effet sur les bénéfices. Les secteurs où les prélèvements sont faibles - et par conséquent où l'hétérogénéité entre pays est faible - présentent des effets de profit beaucoup plus faibles et une variation plus faible entre les pays que les secteurs où seuls certains pays ont des niveaux de prélèvement élevés dans le statu quo. En outre, la variation des effets sur les bénéfices entre les pays est également déterminée par la nature de l'expérience les scénarios qui harmonisent les prélèvements à une certaine valeur génèrent une plus grande variation des bénéfices que les changements de prélèvement par une valeur en pourcentage ou par un niveau de prélèvement absolu.

La grande hétérogénéité des effets des changements de prélèvement sur les bénéfices est confirmée par un modèle statique basé sur les données sectorielles de coût et de rentabilité de l'électricité et permettant la répercussion des coûts aux niveaux suggérés par les études sectorielles. Ce modèle est évalué pour les dix secteurs couverts par l'étude. Toujours dans ce modèle, les changements (réductions) de rentabilité sont les plus élevés dans les scénarios supposant une harmonisation des prélèvements ou un passage de prélèvements effectifs à des niveaux de prélèvements complets non exonérés.

Enfin, pour comparer ces différents contrefactuels, nous évaluons les compromis entre trois objectifs politiques principaux: i) collecter le budget le plus important possible pour les SER et la cogénération afin de soutenir le Green Deal européen, ii) limiter la distorsion de concurrence au sein de l'UE existant dans le statu quo en raison des différents niveaux de prélèvement entre les pays et iii) limiter un impact négatif potentiel sur les bénéfices générés par les changements de prélèvement, qui pourrait déclencher la délocalisation des entreprises à long terme. Nous constatons que les scénarios qui subordonnent les exemptions à la condition que le prélèvement total dépasse un certain seuil sont les plus à même de résoudre les compromis entre ces objectifs politiques. Cette option suppose des exemptions de prélèvement uniquement pour les pays qui affichent un niveau de prélèvement total supérieur au seuil dans le statu quo et pour les entreprises éligibles aux exemptions dans le statu quo. Un tel scénario permettrait d'augmenter le budget disponible et de réduire l'hétérogénéité des prélèvements - et donc des distorsions de concurrence. En outre, selon nos estimations, il serait peu probable qu'il entraîne de fortes réductions de rentabilité dans la plupart des pays et des secteurs, ce qui limiterait le risque de délocalisation.

Kurzfassung (DE)

Einführung und Studienauftrag der Kommission

Im Rahmen der Überarbeitung der aktuellen Beihilfevorschriften hat die Generaldirektion Wettbewerb der Europäischen Kommission (DG COMP) das Konsortium bestehend aus E.CA Economics, DIW Berlin, LEAR, Sheppard Mullin und University of East Anglia (UEA) mit einer externen Studie beauftragt, um die Kommission bei der Überarbeitung der EU-Leitlinien für staatliche Umweltschutz- und Energiebeihilfen (UEBLL) und der Allgemeinen Gruppenfreistellungsverordnung (AGVO) in Bezug auf Umwelt- und Energiebeihilfen zu unterstützen.

Die Studie befasst sich mit den folgenden drei Hauptthemen ("Studienpunkte"):

- **Studienpunkt 1: Transparenz, Ausschreibungen und Ausweitung.** Die umfassenden Investitionen, die für den Übergang zu einer kohlenstoffarmen Wirtschaft erforderlich sind, rechtfertigen es, eine mögliche Überarbeitung der Regeln zu erwägen, die sicherstellen, dass staatliche Beihilferegelungen für den Umweltschutz und die industrielle Dekarbonisierung kosteneffizient sind (d.h. die Kosten zur Erzielung von Umweltvorteilen minimieren) und den Wettbewerb nicht unangemessen verzerren (d.h. die Umweltbeihilfe ist verhältnismäßig und auf das Notwendige beschränkt). Vor diesem Hintergrund wird in Studienpunkt 1 untersucht, ob und wie die Transparenz der Umweltschutzkosten von Beihilfemaßnahmen im Bereich der Dekarbonisierung erhöht werden sollte, indem sowohl der Nutzen für den Umweltschutz als auch dessen Kosten quantifiziert werden. Des Weiteren wird untersucht, ob die Ausschreibungspflicht bei Beihilferegelungen ausgeweitet werden sollte. Schließlich wird untersucht, ob Umweltschutzmaßnahmen auf verschiedene Branchen und Technologien ausgeweitet werden können, die das gleiche Umweltschutzziel in ähnlichem Umfang fördern können, anstatt branchen- oder technologiespezifisch zu sein.
- **Studienpunkt 2: Betriebs- und Investitionsbeihilfen.** In der aktuellen UEBLL und AGVO spielt die Unterscheidung zwischen Betriebs- und Investitionsbeihilfen eine wichtige Rolle. Die Herausforderungen des Übergangs in eine grüne Wirtschaft könnten jedoch neue Arten von Beihilfen und ein Überdenken der traditionellen Unterscheidung zwischen Betriebs- und Investitionsbeihilfen erfordern. Daher untersucht Studienpunkt 2 die Effektivität und den wettbewerbsverzerrenden Effekt verschiedener Beihilfeformen, indem die vorhandene Literatur begutachtet, Fallstudien zu vier repräsentativen Beihilfemaßnahmen durchgeführt und hypothetische zukünftige Beihilfemaßnahmen in wichtigen Branchen modelliert werden.
- **Studienpunkt 3: Energieintensive Nutzer**. Das Ziel von Studienpunkt 3 ist ein zweifaches: Erstens wird bewertet, ob die wirtschaftlichen Parameter, die derzeit in den UEBLL 2014 verwendet werden, um die Auswahl von Wirtschaftszweigen für die Möglichkeit zur Befreiung von Dekarbonisierungsabgaben für energieintensive Nutzer ("EIU") zu bestimmen, aus wirtschaftlicher Sicht die relevantesten Parameter für das Risiko einer Verlagerung sind. Zweitens soll ermittelt werden, inwieweit die Rentabilität von EIUs durch unterschiedliche Niveaus von Abgaben für erneuerbare Energiequellen (EE) und Kraft-Wärme-Kopplung (KWK) auf Strom in 10 ausgewählten Wirtschaftszweigen beeinflusst wird.

Der Bericht ist entlang der drei Studienpunkte gegliedert (Kapitel 1, 2 bzw. 3). Die Anhänge enthalten ergänzende Informationen zu den jeweiligen Studienpunkten, wie Literaturlisten, zusätzliche Grafiken und Ergebnisse sowie Robustheitsüberprüfungen.

Hauptergebnisse für Studienpunkt 1: Transparenz, Ausschreibungen und Ausweitung

Eine erhöhte Transparenz von Umweltbeihilfemaßnahmen würde die Bewertung von Kosten und Nutzen der Beihilfe erleichtern. Um die Kommission dabei zu unterstützen, solche Kosten und Nutzen in einer einheitlichen Weise zu messen, zumindest für die Förderung von CO_2-Emissionsminderungsmaßnahmen, bietet dieser Bericht einen Überblick über die verfügbare akademische Forschung und Studien darüber, wie die Kosteneffizienz von Emissionsminderungsmaßnahmen gemessen werden kann. Die Ergebnisse sind möglicherweise nicht auf andere Bereiche des Umweltschutzes, wie z. B. Kreislaufwirtschaft und saubere Mobilität, anwendbar. Die Kosteneffizienz von Emissionsminderung wird im Allgemeinen in EUR pro Tonne vermiedener CO_2- oder CO_2-Äquivalent-Emissionen (€/tCO_2 oder €/tCO_2ä) gemessen. Die Kosten werden in der Regel als der Betrag der Förderung abzüglich des monetarisierbaren Nutzens (z. B. Einsparungen bei den Brennstoffkosten, CO2-Kosten und Kapazitäten) berechnet. In der untersuchten Literatur beschränkt sich die Bewertung der geminderten CO_2-Emissionen auf die Emissionsreduktionen in dem Markt, auf den die Maßnahme direkt abzielt, und im Falle der Förderung erneuerbarer Energien auf den Stromsektor. Es kann jedoch relevant sein, die Emissionsminderungs- und Preisinteraktionseffekte mit sich überschneidenden Dekarbonisierungsmaßnahmen, wie dem EU-Emissionshandelssystem, zu bewerten. Wenn sie mit einem Emissionshandelssystem koexistieren, können Emissionsminderungsmaßnahmen den CO_2-Preis senken, während die Emissionen nur an andere Orte verlagert werden ("Wasserbett-Effekt"). In der Literatur wird die Relevanz eines solchen Effekts bei der Bewertung der Kosteneffizienz diskutiert. Die akademische Forschung mahnt auch die Notwendigkeit an, Spillover-Effekte auf andere Sektoren (z.B. Industrie, Heizung, Transport), Verhaltensreaktionen, Lerneffekte und die Auswirkungen auf Biodiversität und natürliche Ökosysteme zu berücksichtigen. Die Bewertung von Lerneffekten würde eine langfristige Perspektive erfordern: Unausgereifte Technologien können ein großes Potenzial zur zukünftigen Kostensenkung haben und daher langfristig gesehen kosteneffizient sein. Bei der Bewertung der Kosteneffizienz kann es einen Zielkonflikt zwischen kurz- und langfristigem Horizont geben. Einerseits kann es sein, dass politische Maßnahmen, die kurzfristig kosteneffizient sind, es nicht erlauben, die langfristigen Emissionsziele zu den geringstmöglichen Kosten zu erreichen. Andererseits besteht, da Investitionen irreversibel sind, für politische Entscheidungsträger das Risiko, sich auf eine veraltete Technologie festzulegen, die möglicherweise auch langfristig nicht kosteneffizient wird.

Die Literaturübersicht zeigt, dass sich die Mitgliedstaaten zunehmend auf das €/tCO_2-Kriterium stützen oder dies planen, um die Förderung für erneuerbare Energien und andere Emissionsminderungsmaßnahmen zu vergeben oder deren Wirksamkeit zu bewerten. Dies deutet darauf hin, dass es von Vorteil ist, von Ansätzen abzurücken, bei denen die zu fördernden Maßnahmen auf der Grundlage der Kosten pro Energieeinheit (€/kWh erzeugter Energie) ausgewählt werden, die jegliche Umweltkosten und -vorteile außer Acht lassen. Die Kosteneffizienzkennzahl sollte eine bessere Bewertung des Beitrags zum angestrebten Umweltziel und der Verhältnismäßigkeit der Beihilfe ermöglichen; außerdem sollte sie dazu beitragen, Maßnahmen zu identifizieren, die ungewöhnlich hohe Kosten verursachen und eine weitere Prüfung oder strengere Vereinbarkeitsbedingungen erfordern. Wie oben erwähnt, zeigt die Überprüfung der Literatur, dass es einige Vorbehalte zu beachten gibt (z. B. Einbeziehung positiver oder negativer Umweltexternalitäten) und dass die Kennzahl weiter verfeinert werden könnte

Mit den UEBLL 2014 wurde als allgemeine Anforderung zur Gewährung von Beihilfen für die Stromerzeugung aus erneuerbaren Energiequellen eingeführt, dass diese wettbewerblich vergeben werden müssen. Die Begründung dafür ist, dass Auktionen durch die Stimulierung des Wettbewerbs unter den potenziell Begünstigten die technologische Entwicklung fördern, das Risiko einer Überkompensation vermeiden und ganz allgemein zu einer Minimierung der Förderkosten führen können. In Punkt 1 der Studie wird untersucht, unter welchen Bedingungen zu erwarten ist, dass Auktionen hinreichend wettbewerbsintensiv sind und somit zu einer Kostenermittlung sowie zu einer Verhältnismäßigkeit der Beihilfen führen. Die Literaturrecherche stützt sich hauptsächlich - aber nicht ausschließlich - auf die vorhandenen Arbeiten zu Auktionen für die Erzeugung erneuerbarer Energien. Nichtsdestotrotz sind die allgemeinen Erkenntnisse auf jedes Auktionssystem anwendbar. Die Literatur zeigt, dass das Auktionsdesign einen Einfluss auf die Teilnahme, den Wettbewerb und damit auch auf das Bietverhalten haben kann. Die wichtigsten Gestaltungselemente, die die Ergebnisse der Auktionen beeinflussen können, sind die Preisregeln (Pay-as-bid oder Einheitspreisverfahren), die Formate (statisch, dynamisch oder hybrid) und die Bewertungsregeln (nur auf dem Preis oder auf mehreren Faktoren basierend). Schließlich gibt es eine Debatte darüber, ob Auktionen technologieneutral - d.h. offen für alle verfügbaren Technologien, die unter einem gemeinsamen Budget konkurrieren würden - oder technologiespezifisch sein sollten. Obwohl technologieneutrale Auktionen zumindest kurzfristig zu einer Kostenminimierung führen können, können sie auch die teuersten Technologien ausschließen und Mitnahmegewinne für die preiswertesten Technologien generieren. Technologiespezifische Auktionen können die Technologievielfalt fördern und die Versorgungssicherheit erhöhen. Schließlich deuten die Erfahrungen in einigen Mitgliedstaaten darauf hin, dass Auktionen auch zur Förderung anderer emissionsarmer Technologien als der Stromerzeugung aus erneuerbaren Energien eingesetzt werden (z. B. Energieeffizienzmaßnahmen und Kraft-Wärme-Kopplungsanlagen in Deutschland). Diese Erkenntnisse werden für die Kommission von Nutzen sein, um zu beurteilen, ob und inwieweit Ausschreibungen auf weitere Bereiche ausgedehnt werden sollten.

Um die Kommission bei der Bewertung zu unterstützen, inwieweit Umweltschutz- und Emissionsminderungsmaßnahmen auf mehrere Branchen und Technologien ausgeweitet werden sollten, stützt sich Studienpunkt 1 sowohl auf eine Literaturübersicht als auch auf eine Fallstudienanalyse.

Im letzten Jahrzehnt haben die Mitgliedstaaten zunehmend auf technologieübergreifende Regelungen zur Förderung der Stromerzeugung aus erneuerbaren Energiequellen und auf branchenübergreifende Regelungen zur Dekarbonisierung gesetzt. Während technologieneutrale Regelungen den Einsatz von Technologien ohne jegliche Diskriminierung zwischen Technologien und Branchen unterstützen, fördern Multi-Technologie- und Multi-Branchenregelungen ausgewählte und mehrere Technologiebereiche und Branchen. In beiden Fällen konkurrieren mehrere Technologien und Branchen unter demselben Budget. In der Literaturübersicht werden die Ergebnisse solcher erweiterter Programme vorgestellt. Die wichtigste Erkenntnis ist, dass die Ausweitung von Förderregelungen auf Branchen und Technologien, die ähnliche Umweltziele verfolgen, dazu beitragen könnte, den Beihilfebetrag zu minimieren, und somit zu einer kosteneffizienteren Politik führen könnte. Nichtsdestotrotz kann ihre Umsetzung einige Risiken bergen. Multi-Technologie-Auktionen für die EE-Förderung können das Risiko bergen, innovative Technologien zu verdrängen und die Akteursvielfalt zu verringern. Branchenübergreifende Programme zur Unterstützung der Dekarbonisierung erfordern Umrechnungsfaktoren, um die Auswirkungen auf die CO_2-Emissionen zu bewerten, und der Preis für jede Technologie wird in € pro tCO_2 (oder CO_2-Äquivalent) ausgedrückt, welche vermieden wird. Obwohl es einige Vorteile gegenüber Maßnahmen gibt, die die Begünstigten auf der Basis von €/kWh auswählen, kann es schwierig sein, eine Methode zu finden, die es erlaubt, sowohl die Emissions- als auch die Kostenreduzierung auf faire Weise über mehrere Technologien und Branchen hinweg zu berechnen. Darüber hinaus können breiter angelegte Ausschreibungen über mehrere Branchen hinweg durch die Verstärkung des Wettbewerbs zwischen den Bietern im Rahmen eines einzigen Budgets das Risiko von Unterbietungen erhöhen.

Die Fallstudienanalyse basiert auf Förderprogrammen für Wind, Solar, Kraft-Wärme-Kopplung (KWK) und Energieeffizienz, die in Dänemark, Deutschland und Polen umgesetzt wurden. Die Methodik baut auf einem konzeptionellen Rahmen auf, der bewertet, wie die Treibhausgasemissionen durch die verschiedenen untersuchten Technologien in aktuellen und zukünftigen Strom- und Energiesystemen reduziert werden und welche Unterstützung für die Emissionsminderung in den kommenden Jahren erforderlich sein wird.

Die rückblickende Bewertung der Kosteneffizienz zeigt, dass das Gesamtniveau der Kosten für die Emissionsminderung für Solar-, Wind- und Energieeffizienzmaßnahmen mit Ausnahme der KWK ähnlich ist. Für KWK gibt es starke Unterschiede, die durch Unterschiede sowohl innerhalb als auch zwischen den Ländern in der absoluten Höhe der Zahlungen und der Emissionsminderungseffekte der vermiedenen und erzeugten Emissionen bedingt sind.

Während die Vermeidungskosten der Förderung von gasbefeuerten Anlagen in Polen mit denen der EE-Technologien vergleichbar sind, haben KWK-Auktionen in Deutschland etwa zweimal und die administrative KWK-Förderung in Dänemark etwa viermal höhere Vermeidungskosten als die Förderung von Wind- und Solaranlagen. Wenn umweltschädlichere Technologien gefördert werden - z. B. ölbefeuerte KWK-Anlagen, die im deutschen Förderprogramm teilnahmeberichtigt sind, oder kohlebefeuerte Anlagen, die im polnischen Förderprogramm teilnahmeberichtigt sind -, haben diese Technologien zwei- bis dreimal so hohe Minderungskosten im Vergleich zu gasbefeuerten Anlagen. Während die Ergebnisse robust gegenüber den Annahmen zur Abregelung und Marktwerten von Technologien sind, können andere Parameter wie Diskontierungssätze und angenommene Verdrängungseffekte die Ergebnisse beeinflussen und Vergleiche zwischen zwei Gruppen von Kosteneffizienzanalysen erschweren. Obwohl es andere Vorteile für die Unterstützung von KWK geben kann, könnten im Ergebnis KWK-Anlagen eine deutlich weniger kosteneffiziente Art der Dekarbonisierung sein als Wind- und Solarenergie sowie die anderen untersuchten Energieeffizienzmaßnahmen.

Obwohl es Schwierigkeiten bei der Berechnung der Kosten pro tCO_2 gibt und eine solches Kennzahl möglicherweise nicht alle mit einem bestimmten Projekt verbundenen Vorteile berücksichtigt, könnte €/tCO_2 einen besseren Anhaltspunkt auf den relativen Emissionsminderungsnutzen verschiedener Projekte geben als das üblichere Maß von €/kW oder €/kWh.

Eine dynamische und statische kontrafaktische Simulationsanalyse, die technologiespezifische und technologieübergreifende Ausschreibungen vergleicht, basierend auf einem harmonisierten €/tCO_2-Kriterium über alle Technologien hinweg und in Anlehnung an die Kosteneffizienzbewertung, zeigt gemischte Ergebnisse. Für die Simulation nehmen wir Auktionen im Einheitspreisverfahren, perfekten Wettbewerb und vollständige Information an und ignorieren dynamische Effekte sowie andere Umwelt- und Systemauswirkungen. In Polen und Dänemark überwiegen die Kosteneinsparungen durch die Abkehr von teureren Technologien (z.B. KWK) die potenziellen Mitnahmegewinne aus gemeinsamen Clearing-Preisen und führen zu einer Reduktion der Vermeidungskosten von 6-7%. Im deutschen Fall wurden für ein Jahr Kosteneinsparungen von 6% berechnet, während in zwei Jahren Multi-Technologie-Auktionen die Kosten um 5% erhöht hätten. In diesen Fällen resultiert das bessere Abschneiden technologiespezifischer Auktionen aus einer technologieinternen Preisdiskriminierung im Fall von Windenergie an Land. Wir nehmen dabei an, dass allokative Ineffizienzen, die zu einer Auswahl von windarmen gegenüber windreichen Standorten führen, begrenzt sind.

Die Einführung von Preis-(oder Gebots-)Obergrenzen für bestimmte Technologien in Multi-Technologie-Auktionen hat eine begrenzte Wirkung. Preisobergrenzen verbessern das Abschneiden der Multi-Technologie-Auktion im dänischen Simulationsfall, indem sie Mitnahmegewinne für Photovoltaik und Wind an Land in dem Fall vermeiden, in dem Offshore-Wind den Preis bestimmt. Dies führt zu ca. 9% niedrigeren Vermeidungskosten im Vergleich zu Multi-Technologie-Auktionen ohne Preisobergrenzen. In Deutschland führen Preisobergrenzen dazu, dass ein Teil des Potenzials der günstigeren Technologien ausgeschlossen wird, wenn sie zu niedrig angesetzt werden.

Die Ausweitung der statischen auf eine dynamische Simulation von 2020 bis 2030 ermöglicht eine Bewertung der Rolle, die begrenzte Technologiepotenziale und Lieferketteneffekte durch variierende Nachfrageniveaus spielen könnten: Während in einem Fall ohne diese Effekte technologieübergreifende Ausschreibungen geringfügig niedrigere Vermeidungskosten von etwa 1 % aufweisen, erhöht die Einbeziehung dieser Effekte die Kosten von technologieübergreifenden Ausschreibungen um etwa 2 %, so dass technologiespezifische Ausschreibungen geringfügig niedrigere Vermeidungskosten aufweisen, wenn diese Effekte berücksichtigt werden. Dieser Effekt verstärkt sich mit geringerem Potenzial der Erneuerbaren Energien.

Die kontrafaktischen Simulationen zeigen zusammenfassend, dass ein Wechsel von technologiespezifischen zu technologieübergreifenden Auktionen in einer statischen Situation zu einer Reduzierung der Vermeidungskosten um 6 % führen kann (Dänemark und Polen). In Ländern, in denen eine technologieübergreifende Auktion eine Preisdiskriminierung innerhalb einer Technologie ausschließen würde und in denen wir davon ausgehen, dass allokative Ineffizienzen begrenzt sind (Deutschland), kann dies in einigen Jahren auch zu einer Erhöhung der Vermeidungskosten um 6 % führen. Wo Multi-Technologie-Auktionen zu hohen Mitnahmegewinnen für infra-marginale Technologien führen (Dänemark), können die Vermeidungskosten durch technologiespezifische Preisobergrenzen gesenkt werden. In Fällen, in denen Gebotsobergrenzen kosteneffiziente Technologiepotenziale ausschließen (Deutschland), können sie hingegen die Vermeidungskosten erhöhen.

Wenn man davon ausgeht, dass die Standorte für Wind- und Solarenergie insgesamt begrenzt sind, dann finden wir in einer dynamischen Simulation Kosteneinsparungen durch Multi-Technologie-Auktionen von 1% im Vergleich zu einer technologiespezifischen Auktion. Wenn zusätzlich die Lieferketteneffekte volatiler Technologienachfrage berücksichtigt werden, dann zeigen technologiespezifische Ausschreibungen Kosteneinsparungen von 1 %.

Hauptergebnisse für Studienpunkt 2: Investitions- und Betriebsbeihilfen

Der Bericht stellt der Kommission Daten, Analysen und Expertenmeinungen zu den Auswirkungen der Gewährung staatlicher Beihilfen in Form von Investitionsbeihilfen einerseits oder in Form von Betriebsbeihilfen andererseits zur Verfügung. Diese Informationen können der Kommission bei der Beurteilung helfen, ob diese Unterscheidung noch gerechtfertigt ist und ob die Vereinbarkeitsregeln für Investitions- und Betriebsbeihilfen angeglichen werden sollten.

Der Bericht stellt Evidenz in drei Hauptbereichen zur Verfügung:

- Literaturüberblick zur Effektivität der Unterscheidung zwischen Betriebs- und Investitionsbeihilfen im Rahmen der UEBLL; die begutachtete Literatur konzentrierte sich hauptsächlich auf Beihilfen im Bereich der Förderung von umweltfreundlicher Energieerzeugung;
- Vergleich von Betriebs- und Investitionsbeihilfen für vier konkrete Beihilfeprogramme im Bereich der UEBLL und der AGVO; und
- Hypothetische Förderprogramme für industrielle Dekarbonisierung mit Auswirkungen auf drei Industriezweige: Stahl, Zement und Düngemittel (Ammoniak).

Der Literaturüberblick zeigt, dass im Bereich der Förderung der umweltfreundlichen Energieerzeugung Betriebsbeihilfen zur Sicherung von Investitionen effektiver waren als Investitionsbeihilfen. Teilweise wird dies auf den Umstand zurückgeführt, dass die Höhe der gewährten Investitionsbeihilfe zu niedrig war.

Beide Arten von Beihilfen tragen zur wirtschaftlichen Durchführbarkeit von Umweltschutzmaßnahmen bei, leisten dies jedoch auf unterschiedliche Weise, was den Schluss nahelegt, dass beide Beihilfearten immer noch eine wichtige Rolle spielen könnten.

Allerdings erscheint die Unterscheidung zwischen Betriebs- und Investitionsbeihilfen im Hinblick auf Umweltschutzbeihilfen weniger klar als in anderen Bereichen, da viele Projekte kapitalintensiv sind, so dass verschiedene Kombinationen von Investitions- und Betriebsbeihilfen zu solchen Investitionsentscheidungen anregen können. Bei den Erwägungen eines Unternehmens, in Energie- oder Industrieinfrastrukturen zu investieren, spielt häufig die Aussicht auf Betriebsbeihilfen eine Rolle. Ebenso können Investitionsentscheidungen aus rein finanzieller Sicht durch Investitions- oder Betriebsbeihilfen bzw. durch eine Kombination der beiden beeinflusst werden.

In der Praxis scheinen Betriebsbeihilfen häufiger gewährt zu werden, während Investitionsbeihilfen nach den geltenden Vorschriften (begrenzt auf bestimmte maximale Beihilfeintensitäten) die erhöhten Investitionskosten nicht immer abdecken können. Dabei wurden bereits Lösungswege für angemessene Anreize für Energieinvestitionen gefunden, wobei für einige neue Energieinvestitionen die Höhe der Beihilfen wettbewerblich auf null reduziert werden konnte, was darauf hindeutet, dass staatliche Beihilfen für bestimmte Kategorien von Energieinvestitionen möglicherweise zunehmend unnötig werden, da der Markt aufgrund sinkender Investitionskosten und steigender Nachfrage nach erneuerbaren Energien, gegebenenfalls durch externe Unterstützung für die Netzkosten, alleine die erforderlichen Investitionen aufbringen kann.

Die Auswertung der Literatur zum wettbewerbsverzerrenden Effekt von Betriebs- und Investitionsbeihilfen zeigt, dass preisbasierte Betriebsbeihilfen in Kombination mit niedrigen Grenzkosten von PV, Wind und Wasser einen wettbewerbsverzerrenden Effekt auf die Märkte haben können und in einigen Fällen negative Preise verursachen. Niedrige oder negative Marktpreise können das Vertrauen der Investoren beschädigen und zu subventionsgesteuerten Investitionsentscheidungen führen, die wiederum in subventionsbasierte Pfadabhängigkeiten münden können.

Einige Beihilfeformen (Einspeisetarife) erwiesen sich als stärker marktverzerrend als andere (Einspeiseprämie), da Einspeisetarife die Erzeuger vollständig vom Marktrisiko und den Reaktionen auf Marktsignale abschirmen. Daher müssen die politischen Entscheidungsträger bei der Gestaltung von preisbasierten Betriebsbeihilfeinstrumenten den potenziell wettbewerbsverzerrenden Effekt von Beihilfen berücksichtigen.

Auch weitreichendere Lösungen wie der Übergang von preisbasierten zu kapazitätsbasierten Zahlungen werden von Stimmen aus der Forschung vorgeschlagen.

Um besser nachvollziehen zu können, wie energiebezogene Investitions- und Betriebsbeihilfen als Anreiz für Investitionen und zur Erzielung von gewünschten Vorteilen in der Praxis funktionieren, werden vier Beihilfeprogramme detailliert untersucht. Dies führt zu einem genaueren Verständnis der Auswirkungen von Investitions- und Betriebsbeihilfen auf verschiedene Technologiearten. Bei diesen Programmen handelt es sich um ein PV-Programm mit Investitionsbeihilfe, ein Biogasprogramm mit Betriebs- und Investitionsbeihilfen, ein KWK-Programm mit Betriebs- und Investitionsbeihilfen und ein KWK-Programm für Erdgas mit Betriebsbeihilfe. Das PV-Investitionsbeihilfeprogramm wurde eingestellt, da aufgrund des Beihilfeniveaus eine private Rentabilität nicht möglich war.

Bei der Förderung von PV-Betriebsbeihilfen kam es bei einer Vergleichsregelung zu starken Schwankungen des Investitionsniveaus, da die administrativ festgelegte Betriebsbeihilfe die schnell sinkenden Investitionskosten der PV nicht erfassen konnte, was zu einem Anstieg der Investitionen führte, als die Förderung hoch war, gefolgt von einem Rückgang der Investitionen, als die Förderung reduziert wurde. Wettbewerblich festgelegte Förderhöhen scheinen eine Lösung für dieses Problem zu bieten, da sie eine genauere Kostenermittlung ermöglichen.

Die Dekarbonisierung in der Industrie scheint weniger entwickelt zu sein als die Dekarbonisierung der Energieerzeugung. Während die Dekarbonisierung der Industrie einige Komplexitäten der Energiesektordekarbonisierung mitumfasst, z.B. die Existenz verschiedener Technologien mit unterschiedlichen Kosten, gibt es insofern Unterschiede, als dass: (1) einige Industriebranchen viel wirtschaftlicher dekarbonisiert werden können als andere, (2) die untersuchten Industrien im Allgemeinen unterschiedliche Endprodukte herstellen, die keine Substitute sind, wohingegen die Produkte bei der Energieerzeugung zumindest bis zu einem gewissen Grad Substitute darstellen, und (3) die Betriebskosten nach der Investition im Vergleich zur vorherigen Industrietechnologie oftmals nicht sinken, wohingegen bei den Wind- und PV-Investitionen die variablen Kosten der Energieproduktion im Vergleich zu den vorherigen fossilen Brennstofftechnologien gesenkt wurden.

Vergleiche zwischen potenziellen Programmen für Industrie-Dekarbonisierung deuten darauf hin, dass eine Investitionsbeihilfe in Höhe von etwa 40% der förderfähigen Kosten (d.h. zusätzliche Investitionskosten) wahrscheinlich keine wesentlichen Anreize für große und teure Investitionen schafft, es sei denn, die Betriebskosten sinken im Vergleich zur herkömmlichen Technologie oder die staatlich auferlegten Abgaben für die herkömmliche Produktion werden erhöht. Es könnten Beträge, die deutlich über den 40% liegen, notwendig sein, um die Nutzung dieses Finanzierungsmechanismus voranzutreiben; auch ein Niveau von 50% bis 70% erscheint nicht als ausreichend. Eine hundertprozentige Förderung könnte das Problem beseitigen, wenn die Betriebskosten für die neuen Technologien im Vergleich zur vorherigen Technologie unverändert bleiben.

Eine flexiblere Option bestünde darin, Unterstützung für neue Projekte zu gewähren, welche das Verhältnis zwischen Investition, Betriebskosten und Erträgen über die gesamte Dauer des Projekts berücksichtigt. Diese Art der Förderung könnte Anreize für Investitionen in neue Technologien schaffen. Allerdings birgt sie auch das Risiko, dass die Kosten höher als das benötigte Minimum sind, wenn die Bewilligungsbehörden im Vergleich zu den Unternehmen asymmetrische Informationen über die tatsächlichen Kosten und den tatsächlich benötigten Beihilfebetrag haben. Dies kann die Kosten in den Beihilfeanträgen in die Höhe treiben, auch wenn die Unternehmen fortlaufend geringere Anreize aufgrund des fehlenden externen Effizienzdrucks haben. Diese beiden Schwächen würden ausgeglichen, wenn die Bewilligungsbehörden über ein umfassendes Verständnis des effizienten Kostenniveaus verfügten.

CO_2-Differenzkontrakte (CCfD) bieten eine Reihe von Vorteilen, bergen aber auch Risiken in sich. Zu den Vorteilen gehört die Schaffung eines stabilen langfristigen Investitionsklimas durch die Festlegung fester CO_2-Kosten (und des Werts der CO_2-Reduktion) für den Investor. Der prozentuale Anteil an Eigenkapital, der für die Finanzierung eines CCfD erforderlich ist, kann im Vergleich zu Investitionen ohne CCfD sinken, was letztlich bedeutet, dass staatliche Finanzmittel ein größeres Gesamtinvestitionsvolumen mobilisieren können. Zu den Nachteilen gehört, dass bei einem CCfD dennoch der Staat (oder staatliche Stellen) das Risiko von ETS-Preisschwankungen, Marktmachtrisiken und potenziell höheren Kosten aufgrund des fehlenden externen Wettbewerbsdrucks tragen muss. Ein besonders wichtiger Zielkonflikt zwischen der Dekarbonisierung spezifischer Industrien und Effizienzgesichtspunkten lässt sich bei der Frage beobachten, ob die Preise für CCfD-Ausschreibungen innerhalb einer Industrie oder industrieübergreifend festgelegt werden sollen. Bei Stahl und Ammoniak wäre der Wettbewerb der etablierten Unternehmen in Ausschreibungsprozessen innerhalb derselben Industrie begrenzt, da es in 20 Mitgliedstaaten lediglich 1 oder 0 bestehende Stahlwerke und in 18 Mitgliedstaaten lediglich 1 oder 0 bestehende Ammoniakwerke gibt. Wenn CCfD-Ausschreibungsverfahren industrieübergreifend durchgeführt werden, wird die Effizienz gesteigert, jedoch werden einige Industrien wahrscheinlich eine höhere Dekarbonisierung erreichen als andere, da CO_2-Reduktionen bei einigen Produktionstechnologien mit geringeren Kosten verbunden sind als bei anderen.

Hauptergebnisse für Studienpunkt 3: Energieintensive Nutzer

Basierend auf einer Literaturrecherche sind Indikatoren der Strom- und Handelsintensität als relevant für das Standortverlegungsrisiko von Unternehmen anzusehen.

Was die Stromintensität betrifft, so zeigen empirische Studien, dass sehr energieintensive Unternehmen von Energiepreiserhöhungen (einschließlich Abgaben) in hinsichtlich verschiedener Dimensionen negativ betroffen sind: Produktion, Produktivität, Beschäftigung, Wahrscheinlichkeit des Ausscheidens aus dem Markt, Exporte und Importe. Gleichzeitig zeigen diese Studien, basierend auf einer Stichprobe von energieintensiven und nicht-energieintensiven Unternehmen, keine statistisch oder ökonomisch signifikanten Auswirkungen für ein durchschnittliches Unternehmen. Die unterschiedlichen Auswirkungen auf energieintensive und nicht-energieintensive Unternehmen unterstreichen die Relevanz der Stromintensität als wichtiges Kriterium in den UEBLL.

Hinsichtlich der Handelsintensität bestätigt die Literatur ebenfalls deren Relevanz als Kriterium zur Unterscheidung zwischen Branchen mit hohem und niedrigem Standortverlegungsrisiko aufgrund von Änderungen der Abgabenhöhe. Dieses Ergebnis basiert jedoch nur auf wenigen Studien. Der identifizierte Standortverlegungseffekt ist am stärksten für Branchen, die mit weniger entwickelten Ländern, einschließlich China, handeln. Diese Handelspartner haben oft weniger strenge Regeln zur Emissionsminderung.

Allgemeiner gefasst schlägt die Literatur vor, dass Abgabenbefreiungen auf Branchen mit einem komparativen Energiekostennachteil (d.h. Branchen, die mit Ländern handeln, in denen die Energiekosten niedriger sind als in der EU), auf Branchen mit hoher Kapitalmobilität und auf Branchen, die mit Ländern handeln, die protektionistische Maßnahmen anwenden, ausgerichtet sein sollten. Ein weiterer Vorschlag aus der Literatur ist die Anwendung von produktspezifischen Effizienz-Benchmarks für die Stromintensität pro physischer Produktionseinheit, um Anreize für den Einsatz energieeffizienter Technologien zu schaffen und gleichzeitig die Wettbewerbsfähigkeit zu bewahren.

Die praktische Umsetzung dieser Verbesserungen der Kriterien ist jedoch schwierig. Dies liegt daran, dass es an verlässlichen und regelmäßig aktualisierten Datenquellen mangelt, die es erlauben würden, diese Kriterien branchenübergreifend zu messen und dadurch förderungswürdige von nicht förderungswürdigen Branchen zu trennen. Diese Studie enthält Empfehlungen, wie diese praktischen Beschränkungen abgemildert werden können. Dennoch bleiben einige Fragezeichen hinsichtlich der Machbarkeit ihrer Umsetzung bestehen.

Neben einer kritischen Literaturrecherche bietet die Studie eine Beschreibung der Daten zu den EE- und KWK-Umlagen für 10 ausgewählte Branchen[5] in 11 Mitgliedstaaten[6] ("EU-11") im Zeitraum 2011-2018. Drei weitere Länder erheben ebenfalls EE- und/oder KWK-Umlagen zur Förderung der EE- und KWK-Stromerzeugung, konnten aber aufgrund fehlender disaggregierter Stromverbrauchsdaten nicht analysiert werden (Italien, Rumänien und Estland). Die übrigen EU-Länder erheben keine EE- und/oder KWK-Umlagen. Eine potenziell wichtige Einschränkung der deskriptiven Analysen ist, dass die Abgaben - und die Befreiungen davon - nur für ein Unternehmen mit durchschnittlichem Stromverbrauch in einem bestimmten Land und Branche berechnet werden können. Die deskriptive Analyse bildet daher auch die Abgaben - und die Befreiungen davon - nur für ein Unternehmen mit durchschnittlichem Stromverbrauch in der Branche ab. Die Heterogenität innerhalb einer Branche in Bezug auf die Stromintensität und ihre Auswirkungen auf die Höhe der Abgaben für einzelne Unternehmen innerhalb der Branche können nicht analysiert werden. Trotz dieser Einschränkung erachten wir unsere deskriptiven Analysen als relevant für das Verständnis der branchenübergreifenden Heterogenität und als robust genug, um eine aggregierte Sicht auf die vorliegende Fragestellung zu liefern.

Basierend auf diesen Daten erstellen wir relevante Statistiken für die Gesamthöhe der EE- und KWK-Abgaben und die entsprechenden Befreiungen für den Zeitraum 2011 bis 2018. Wir kommen zu folgenden Ergebnissen:

Erstens stellen wir in Bezug auf die einzelnen Länder fest, dass Deutschland die höchsten und im Zeitverlauf steigenden Gesamtabgaben hat. Die Abgaben variieren im Beobachtungszeitraum zwischen 3 und 7 Eurocent/kWh. Zieht man dagegen die Befreiungen von den Gesamtabgaben ab (und nimmt damit die effektiv wirksamen Abgaben in den Blick), unterliegen die förderfähigen Unternehmen in Deutschland in mehreren Branchen Abgaben, die mit den anderen untersuchten Mitgliedstaaten vergleichbar sind, in denen die effektiven Abgaben zwischen null und 1,5 Eurocent/kWh variieren. Ein Land mit relativ hohen Abgaben, sowohl der gesamten als auch der effektiven, ist Lettland. Dies ist darauf zurückzuführen, dass die gesamte KWK-Abgabe sehr hoch ist und keine Befreiungen gewährt werden. In Polen liegen die Abgaben 2018 in sieben von zehn Sektoren auf dem niedrigsten Niveau. Frankreich erhebt seit 2016 keine Abgaben mehr.

Zweitens, mit Blick auf den EU-11-Durchschnitt, steigen die durchschnittlichen Gesamtabgaben (ländergewichtet nach Umsatz) im Beobachtungszeitraum in sieben der zehn Branchen von etwa 2 auf über 4 Cent/kWh. Dieses Ergebnis ist vor allem auf einen starken Anstieg der Abgaben in Deutschland zurückzuführen, das einen anhaltend hohen Umsatzanteil in den untersuchten Branchen hält und somit den EU-11-Durchschnitt der Gesamtabgaben über den Beobachtungszeitraum wesentlich beeinflusst. Mit Blick auf die effektiven Abgaben, d.h. unter Berücksichtigung von Befreiungen, ist für den EU-11-Durchschnitt der Abgaben nur ein geringer Anstieg zu beobachten. Auch hier ist Deutschland aufgrund seiner wirtschaftlichen Bedeutung in den analysierten Branchen ein wichtiger Treiber für diese Beobachtung.

Während die deskriptive Analyse einige Einblicke in die Abgabenhöhe und die Veränderungen der Abgaben in Branchen, Ländern und über die Zeit bietet, führen wir im nächsten

[5] Diese Branchen umfassen: Herstellung von Vliesstoff und Erzeugnissen daraus (ohne Bekleidung) (NACE-Code C13.95), Herstellung von Furnier-, Sperrholz-, Holzfaser- und Holzspanplatten (C16.21), Herstellung von Holz- und Zellstoff (C17.11), Herstellung von Haushalts-, Hygiene- und Toilettenartikeln aus Zellstoff, Papier und Pappe (C17.22), Herstellung von Industriegasen (C20.11), Herstellung von sonstigen anorganischen Grundstoffen und Chemikalien (C20.13), Erzeugung von Roheisen, Stahl und Ferrolegierungen (C24.10), Erzeugung und erste Bearbeitung von Aluminium (C24.42), Erzeugung und erste Bearbeitung von Kupfer (C24.44), Datenverarbeitung, Hosting und damit verbundene Tätigkeiten (J63.11).

[6] Diese Länder sind Dänemark, Deutschland, Frankreich, Griechenland, Kroatien, Lettland, Litauen, Österreich, Polen, Slowakei and Slowenien.

Schritt eine ökonometrische Analyse und Simulationen durch, um die potenziellen Auswirkungen der Abgaben auf die Rentabilität der Unternehmen zu bewerten. Dies wird für neun Industriebranchen gemacht, für die das ökonometrische Modell identifiziert werden kann.

Zu diesem Zweck führen wir eine branchenspezifische Heterogenität des Stromverbrauchs für verschiedene Unternehmensgrößengruppen ein. Das Verbrauchsband von Eurostat, das durch den durchschnittlichen Stromverbrauch je Land und Branche angegeben wird, wird großen Unternehmen zugeordnet, mittelgroße Unternehmen dem nächstniedrigeren Verbrauchsband und kleine Unternehmen dem jeweils noch niedrigeren Verbrauchsband. Wir schätzen dann die Elastizität der Gewinne in Bezug auf die Strompreise. Diese Elastizität misst die prozentuale Änderung der Profitabilität als Reaktion auf eine prozentuale Änderung der Strompreise, zu denen auch die EE- und KWK-Umlage gehört. Basierend auf diesen Schätzungen simulieren wir kontrafaktische Szenarien für Abgabenänderungen im Jahr 2018.

Um den Einfluss der Abgaben auf die Gewinne zu schätzen, werden fünf verschiedene Klassen von Szenarien entworfen. Zunächst betrachten wir zwei Szenarien mit Gesamtabgaben. In einem Szenario wird die effektive Abgabe in einer Branche auf die höchste branchenspezifische Gesamtabgabe festgelegt, die 2018 beobachtet wurde (die Abgabe in Deutschland). In dem anderen Szenario lassen wir keine Befreiungen zu, d. h. die Gesamtabgaben werden auch als die effektiven Abgaben in einer bestimmten Branche und Land angenommen. Zweitens bewerten wir eine Reihe von Szenarien, in denen wir eine prozentuale effektive Abgabenänderung (Erhöhung oder Senkung) in Bezug auf die effektiven Abgabenniveaus im Status quo betrachten (-50%, -20%, -10%, +10%, +20%, +50%, +100%). Im dritten Szenario nehmen wir eine Erhöhung um einen gleichen Betrag in allen Ländern und Branchen in Cent/kWh in Bezug auf die effektiven aktuellen Abgaben an (+0,5 ct, +1ct, +1,5 ct) an. Im vierten Szenario analysieren wir die Auswirkungen von Abgabenharmonisierung. Hier werden die effektiven Abgaben - über alle Länder und Branchen hinweg - auf vier verschiedene Abgabensätze gesetzt: 0,5 ct/kWh, 1 ct/kWh, 1,5 ct/kWh und 2 ct/kWh, was der Bandbreite der durchschnittlichen Abgaben über alle Branchen entspricht. In einem letzten, fünften Szenario wird angenommen, dass Befreiungen nur gewährt werden, wenn die Gesamtabgabe einen bestimmten Schwellenwert überschreitet. Es werden drei Schwellenwerte gewählt, 1 ct/kWh, 1,5 ct/kWh und 2 ct/kWh. Wir betrachten zwei verschiedene Niveaus von Befreiungen: 75 % und 85 %. In einer Variante erlauben wir auch, dass die Befreiungen nur für den Teil der Gesamtabgabe gelten, der den Schwellenwert überschreitet.

Wir zeigen, dass die ersten beiden Gesamtabgaben-Szenarien zu einem sehr deutlichen Rückgang der Gewinne führen. In den anderen Szenarien variieren die Auswirkungen auf den Gewinn sowohl in Bezug auf die durchschnittlichen Auswirkungen als auch über die Länder hinweg, während die länderübergreifende Heterogenität der Auswirkungen auf den Gewinn auch innerhalb der einzelnen Branchen variiert. Die Variation der Auswirkung auf die Gewinne wird von drei Schlüsselfaktoren getrieben: i) der Höhe der aktuellen effektiven Abgaben, ii) der länderübergreifenden Heterogenität der aktuellen effektiven Abgaben in jeder spezifischen Branche und iii) der Art des Szenarios (prozentuale oder Niveauänderung). Insbesondere die Höhe der aktuellen Abgaben und die länderübergreifende Heterogenität der Abgaben in jeder Branche bestimmen die Heterogenität des Gewinneffekts. Branchen mit niedrigen Abgaben - und folglich geringer länderübergreifender Heterogenität - zeigen deutlich geringere Gewinneffekte und eine geringere Variation zwischen den Ländern als Branchen, in denen nur einige Länder hohe aktuelle Abgabenniveaus haben. Darüber hinaus wird die Variation der Gewinneffekte zwischen den Ländern durch die Art des Ansatzes bestimmt: Szenarien, die die Abgaben auf einen bestimmten Wert harmonisieren, erzeugen eine größere Variation der Gewinne als Abgabenänderungen um einen Prozentwert oder um ein absolutes Abgabenniveau.

Die große Heterogenität der Auswirkungen von Abgabenänderungen auf die Gewinne wird durch ein statisches Modell bestätigt, das auf Branchendaten zu Stromkosten und Rentabilität basiert und eine Kostenüberwälzung in der von Branchenstudien vorgeschlagenen Höhe zulässt. Dieses Modell wird für alle zehn in der Studie berücksichtigten Branchen geschätzt. Auch in diesem Modell sind die Änderungen (Senkungen) der Rentabilität in den

Harmonisierungsszenarien und in dem Reformansatz, das einen Wechsel von effektiven Abgaben zu nicht befreiten Gesamtabgabenniveaus annimmt, am höchsten.

Um diese verschiedenen kontrafaktischen Szenarien zu vergleichen, bewerten wir schließlich für jedes Szenario die Zielkonflikte zwischen drei Hauptzielen möglicher Reformen: i) die Erhebung des größtmöglichen Budgets für erneuerbare Energien und KWK zur Unterstützung des europäischen Green Deals, ii) die Begrenzung der Wettbewerbsverzerrung innerhalb der EU, die aktuell aufgrund der unterschiedlichen Abgabenniveaus in den einzelnen Ländern besteht, und iii) die Begrenzung einer potenziellen negativen Auswirkung auf die Gewinne, die durch die Änderungen der Abgaben entsteht und langfristig eine Standortverlagerung von Unternehmen auslösen könnte. Wir stellen fest, dass Szenarien, die die Befreiungen an die Bedingung knüpfen, dass die gesamte Abgabe einen bestimmten Schwellenwert übersteigt, den Zielkonflikt zwischen diesen Reformzielen am besten auflösen. Ein solcher Reformansatz unterstellt Abgabenbefreiungen nur für Länder, die aktuell ein Gesamtabgabenniveau über einem Schwellenwert aufweisen, und für Unternehmen, die aktuell Anspruch auf Befreiungen haben. Ein solches Szenario würde eine Erhöhung des verfügbaren Budgets ermöglichen und die Heterogenität der aktuellen Abgaben - und damit die Wettbewerbsverzerrungen - reduzieren. Darüber hinaus wäre es nach unseren Schätzungen unwahrscheinlich, dass es in den meisten Ländern und Branchen zu großen Rentabilitätseinbußen kommt, was das Risiko von Standortverlagerungen begrenzt.

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List of abbreviations

AURES II	Auctions for Renewable Energy Support II
BAFA	German Federal Office of Economics and Export Control
BMWi	German Ministry of Economic Affairs and Energy
CCfD	Carbon Contracts for Difference
CCS	Carbon Capture and Storage
CHP	Combined Heat Power
EBIT	Earnings Before Interest and Taxes
EEAG	EU Guidelines on State aid for environmental protection and energy
EIU	Energy-Intensive User
ETS	Emissions Trading System
FDI	Foreign direct investment
FIPs	Feed-in premiums
FITs	Feed-in tariffs
GWh	Gigawatt hours
GBER	General Block Exemption Regulation
KWKG	[German] Kraft-Wärme-Kopplungsgesetz
MWh	Megawatt hours
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaics
RES	Renewable Energy Sources
SDE	Dutch Renewable Energy Support Scheme
SMNE	Share Marginal Non-Emitting

1. Study Item 1: Transparency, tendering and broadening

1.1 Introduction

The results of the Fitness Check as well as the challenges introduced by the recent regulatory climate measures[7] and the European Green Deal[8] suggest that the EEAG and corresponding rules should be revised. First, the Commission is considering whether Member States should increase the transparency of the environmental protection impact of their aid schemes, by quantifying both the benefits to environmental protection and their costs. Second, the Commission is considering whether the tendering requirement, which is currently mainly applied to the allocation of aid measures for renewable energy sources and high efficiency cogeneration plants, should be extended to other fields (e.g. industrial decarbonisation). Third, the Commission is considering whether environmental protection schemes should be broadened to enable participation of different sectors and technologies which could advance the same environmental protection objective to a similar extent rather than being sector or technology-specific.

Study item 1 provides both a literature review (section 1.2), as well as an estimation of the cost-effectiveness of subsidy schemes and a counterfactual simulation analysis of broadening these schemes (sections 1.3 and 1.4) to inform the Commission's revision of the applicable State aid rules. While the literature review covers the three possible revisions of the rules (related to the transparency, tendering, broadening of the schemes), the cost-effectiveness assessment and simulation analysis are focused on exploring the difference in cost-effectiveness of existing schemes, and the benefits and challenges of broadening a single support mechanism based on tendering to multiple technologies and sectors. Both sections are complemented by Annexes 1-5.

1.2 Results of literature review

This section provides the main findings of the literature review and is structured as follows:

- section 1.2.1 reviews the economic literature assessing the measurement of cost-effectiveness of decarbonisation support schemes;
- section 1.2.2 reviews how subsidy schemes for low carbon technologies have been designed and how they compare with each other;
- section 1.2.3 describes the conditions under which a competitive bidding process can lead to minimising support and ensure aid proportionality;
- section 1.2.4 reviews ex-post studies that have assessed multi-technology, technology-neutral and multi-sector schemes, describes their cost-effectiveness and the challenges encountered.

1.2.1 Measuring cost-effectiveness of decarbonisation measures

The cost-effectiveness of decarbonisation subsidy programmes is usually expressed in terms of € per tonne of abated CO_2 or CO_2 equivalent[9], and computed as follows:

$$cost\ effectiveness\ of\ decarbonisation\ support = \frac{support - monetisable\ benefits\ or\ cost\ savings}{mitigated\ CO2\ emissions}$$

[7] The Clean Energy Package (https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en), the Clean Mobility Package (https://ec.europa.eu/commission/presscorner/detail/en/IP_18_3708), the Circular Economy Package (https://ec.europa.eu/environment/circular-economy/first_circular_economy_action_plan.html).
[8] Please see https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.
[9] Carbon dioxide is only one of many greenhouse gases; others include methane, nitrous oxide, and hydrofluorocarbons. Some of the papers and reports reviewed take into account such other gases when computing avoided emissions (Gillingham and Stock, 2018, the reports assessing the Germany Energy Efficiency programs and the Dutch Energy Investment Allowance). To facilitate comparisons, these papers convert costs for reducing non- CO_2 greenhouse gases into CO_2-equivalent units. A complication in developing CO_2-equivalent estimates is that the atmospheric residence time of greenhouse gases varies.

Based on the available literature, this section discusses how to estimate each of the components of the cost-effectiveness measure, and namely, (i) the support, (ii) the benefits or cost savings, (iii) the mitigated CO_2 emissions. The section also discusses whether the cost-effectiveness measurement should include other environmental effects than the CO_2 emissions reduction in the market targeted by the scheme, and the time-horizon to adopt when making the assessment. The findings of this literature review are specific to decarbonisation, and may not be considered applicable to other areas of environmental protection (e.g. circularity and biodiversity). While most of the section is based on the available evidence on the measurement of cost-effectiveness of renewable energy schemes or other low-carbon technologies, there is also a final discussion on which additional metrics are used when assessing energy saving programmes or technologies. Further evidence on the metrics used by tendering authorities to assess the cost-effectiveness of decarbonisation subsidy schemes and energy efficiency programmes is presented in Annex 1.1.1.

The support is generally equivalent to the aid amount, rather than the investment amount. Differently than the investment amount, the aid amount may be limited to the incremental costs of the aided project (eligible costs), when it replaces another equipment, or to the funding gap, when it is directed to an investment in infrastructure.[10]

The monetisable benefits or costs savings generally include fuel and carbon costs savings as well as capacity savings (Marcantonini et al., 2017, Marcantonini et al., 2014).[11] The fuel cost savings come from consuming less fossil fuel for thermal generation. The carbon cost savings come from purchasing fewer European Union Allowances (EUA) under the Emission Trade System (ETS) due to the reduction of CO_2 emissions. In contrast to fuel savings, carbon cost savings are greater for displaced coal generation than for natural gas generation since avoided emissions by displaced coal generation are higher than for natural gas (Marcantonini et al., 2014). The displacement effect of an increased energy supply varies substantially depending on (i) the correlation between availability of the natural resource and time-varying energy demand (e.g. compared to solar, wind availability is correlated to low demand level) (ii) the composition of installed production capacities and their CO_2 intensity (iii) the carbon price.[12]

The capacity savings come from the avoided fixed costs of conventional capacity that can be replaced by capacity from renewable electricity generation. The extent to which renewable generation can substitute for conventional generation is given by the capacity credit[13], which decreases as installed capacity of from renewable sources increases. The capacity savings should also be considered net of balancing and cycling costs (Marcantonini et al., 2014) as unexpected fluctuations of intermittent generation increase supply variability in the short term, thereby implying more balancing operations, start-up and ramping costs of conventional thermal generation plants. However, it should also be considered that in equilibrium conventional technologies with high investment cost (e.g. coal power plants) may be substituted by technologies with lower investment cost (e.g. gas turbines), or altogether replaced by a combination of renewable capacity and storage or flexible demand, as long-term optimisation models typically forecast (Brown et al., 2019).

The mitigated CO_2 emissions achieved through subsidy programmes for RES, are generally computed as the difference in carbon content of the fuel substitution that takes place as a result of the renewable energy injections (Weigt et al., 2013). There is a wide literature

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[10] The EEAG sets out the rules on the proportionality and maximum intensities of the aid for each of the technologies within the scope of application of the guidelines.

[11] Both studies state explicitly that their methodology does not look at the impact on the electricity price but estimate the costs and benefits of RES by analysing the power generation costs. In contrast, the methodology for the case studies of Section 1.3 takes into account the downward pressure on electricity market price that follows the deployment of the measure being aided, therefore internalising fuel, carbon costs, and capacity savings.

[12] Abrell et al. (2017) points out that it would be reasonable to expect wind to replace more coal, and solar to replace gas due to the correlation of wind availability with low demand level and the correlation of solar with high demand level. This may entail higher carbon cost savings for wind compared to solar. However, this hypothesis also depends on the specific merit order (that is, the sequence in which power stations contribute power to the market), and especially on the carbon price, as a fuel switch occurs.

[13] The capacity credit is a measure of the amount of conventional generation that could be displaced by the renewable production without making the system any less reliable (Denny et al., 2007).

that argues that when the emission from electricity generation is priced or the cap is binding – as in the European ETS – an increase in RES-E offers no marginal environmental benefits (e.g. Braathen, 2007, Fischer and Prenoas, 2010, Frondel et al., 2010). This occurs because external factors affecting emissions (such as RES) change the demand for allowances and therefore their price (waterbed effect). The reduction in the EUA price signals the reduction in demand in one part of the ETS and the consequent need for less abatement in other parts of the capped system. In 2004, a report from the German Federal Ministry for Economic Affairs and Energy (BMWi) stressed that the German Renewable Energy Source Act (EEG) would have a zero net effect on European CO2 emissions: RES would trigger a shift in CO2 emissions from the German electricity sector to others (also Marcantonini et al., 2014). These papers however do not consider that the cap is dynamically set: for instance in 2015, the EU has introduced a Market Stability Reserve (MSR) to reduce the surplus of allowances in the EU ETS. Recent literature explicitly points out that the newly introduced MSR rules[14], by adjusting the cap to the market outcome, will alleviate the waterbed effect, at least for some years. Perino (2018) finds that the MSR reduces the waterbed effect substantially, mainly for past abatement efforts, and to a lesser extent, future efforts. [15] Similarly, Burtaw et al. (2018) show that an additional unit of emissions reduction will lead to less than one cancelled allowance: this shows the waterbed effect is mitigated but does not vanish completely. Finally, findings on waterbed effect are not unanimous: the ex-post and empirical analysis of Koch et al. (2014) show that the economic impact of RES deployment on ETS prices is rather modest. This finding is considered in sharp contrast with prior simulation-based studies[16] that predict strong allowance price reductions instead.

When assessing the abatement potential and, in turn, the cost-effectiveness of decarbonisation support schemes, it may be relevant to assess how the abatement effects of the support scheme and the ETS interact with each other. The literature on the measurement of cost-effectiveness focuses on the abatement interaction effect of RES and ETS in the power sector and seems to ignore the downward pressure of RES on EUA price: Weigt et al. (2013) find a consistently positive interaction effect of the two policies in Germany between for the period 2006-2010. In other words, the abatement attributable to RES injections is greater (by 0,5% to 1,5% of emissions) in the presence of ETS than otherwise (Weigt et al., 2013). However, this effect varies widely depending on the influence of the carbon price on the merit order within the interval of generation that is displaced by the RES injection.[17] In this sense, Marcantonini et al. (2014) conclude that the abatement interaction effect of RES support and ETS on the cost of reducing CO_2 emissions in the power sector is ambiguous. For example, an increase in the EUA price causes a change in the merit order and induces a shift of production from coal to gas, thereby reducing the CO_2 emission (i.e. the denominator of the cost-effectiveness measure decreases); at the same time, this shift induces higher fuel cost savings (decreasing in this way the numerator of the cost-effectiveness). To this end, the paper suggests measuring the implicit price of RES policies as the sum of cost of avoided emission and the EUA price (as this is the additional cost paid by consumers). This would allow to capture "the equivalent total carbon price being paid when we think of [RES policies] as a carbon instrument alone (without EU ETS)". The cost-effectiveness and simulations methodologies in section 1.3

[14] The MSR started operating in January 2019. The reserve was introduced to address the surplus of allowances. Each year, the Commission publishes by 15 May the total number of allowances in circulation: if the number exceeds the 833 million allowances threshold, 24% of the total number of allowances in circulation may be placed in the reserve. On the other hand, when the allowances in circulation reach the 400 million threshold, allowances can be released from the reserve. In addition, as from 2023, the MSR will hold as many allowances as the one auctioned the previous year. See https://ec.europa.eu/commission/presscorner/detail/en/MEMO_14_39 and https://ec.europa.eu/clima/policies/ets/reform_en.

[15] Perino (2018) analyses the cumulative effect of an additional ton abated by an ETS installation on the reduction of long-term emissions within the ETS: the study finds that the marginal impact on the long-term cap decreases year by year until it reaches zero for CO_2 abatements occurred in 2018 and later. This is because for each additional allowance banked, the number of allowances moved to the MSR increases by 0.24; the next year, the number of allowances placed in the MSR will change by (1-0.24) x 0.24=0.1824 and so on.

[16] See for instance Van den Bergh et al. (2013), De Jonghe et al. (2009).

[17] Weigt et al. (2013) finds that the abatement interaction effect between RE and ETS is positive when the carbon price puts coals on the margin in place of gas and the RE injection is not so large that it is displacing gas plants that have been moved down the merit order by the CO_2 price.

adopt a similar approach, but more specifically corrects for the reduced impact the EUA price has on electricity prices at higher RES levels.

While the EU ETS is generally considered as the most cost-effective way to reduce GHG emissions in the absence of market failures (see Annex 1.1), a wide literature justifies the combination of ETS and decarbonisation policies to achieve different policy goals and address other market failures. In a dynamic efficiency perspective, dedicated support for renewable energy generation allows to develop more expensive technologies with large potential for cost reductions through learning effects, thereby allowing such technologies to penetrate the market (del Río, 2017). ETS and decarbonisation schemes can also efficiently reinforce each other by removing political barriers (Meckling et al., 2015, 2017) or mitigating rent redistribution effects (Hirth et al., 2013). While this literature does not explicitly deal with the measurement of cost-effectiveness, it provides useful insights on the benefits of providing RES and, more in general, decarbonisation support in addition to the ETS. Such benefits may be however hard to quantify.

Decarbonisation support schemes might generate various environmental effects (other than CO2 reduction) in different markets or sectors beyond those directly targeted by the measure: these can include, *inter alia,* indirect effects, behavioural responses, impact on biodiversity and spillovers and externalities. These effects could represent either a further environmental cost or benefit. The literature does not provide evidence of the inclusion of such costs and benefits in cost-effectiveness measurement: neither in the academic literature or in the policy reports presented in section 1.2.4, such environmental effects are taken into account. However, some academic papers stress their relevance when analysing the effectiveness of climate policies and subsidy programmes (Abrell et al., 2017, Marcantonini et al., 2014, Gillingham and Stock, 2018).[18]

Among the indirect effects, Abrell et al. (2017) consider the foreign carbon offset, i.e. the fuels replaced abroad by the increase in electricity exports stimulated by subsidy programmes for wind and solar in Germany and Spain. The increase of RE supply pushes generators with high marginal costs out of the market, thereby decreasing the wholesale electricity prices, and making generation of electricity more competitive relative to neighbouring countries.[19] Abrell et al. (2017) finds that the assumptions on foreign carbon offset may increase the cost for reducing one tonne of CO2 emissions[20] (which would move from 500 to 1870€ for solar and -5[21] to 230€ for wind[22]). Van der Bergh et al. (2011) also stress the need to take into account behavioural responses to environmental innovations: these are unintended second-order effects ("rebound effects") in stakeholders' behaviours eventually cancelling the environmental gains. For instance, turning the heat up because the cost of doing so has declined due to weatherproofing (Gillingham and Stock, 2018).[23]

[18] Abrell et al. (2017) stress that a caveat of their model is that it is focused on the short-run market impacts and consider only the "direct" economic cost of carbon abatement, i.e. the cost excluding external costs and benefits associated with using RE technologies (e.g. positive externalities, learning by doing). Marcantonini et al. (2014) stress, instead, that their model does not take into account other benefits – whether they are expressed as energy security, innovation, jobs, non- CO_2 emissions – or additional costs as those associated with transmission and distribution. Gillingham and Stock (2018) points out that engineering estimates of the costs of CO_2 reducing technologies fails to take into account indirect effects that can take place in the same market, e.g. fugitive methane emissions during the production/distribution of natural gas.

[19] Abrell et al. (2017) also points out that solar leads to a larger increase in exports, due to the fact that it is mainly producing when demand is higher and when the prices in neighbouring countries is high.

[20] The cost of CO_2 abatement is defined as the economic cost of the feed-in tariff policy (i.e. the feed-in tariff paid per MWh of RES type deducted by revenue earned by selling the RES output into the market) divided by the change in CO_2 emissions.

[21] Abrell et al. (2017) find negative CO_2 abatement costs in Spain: this is because the average revenue per MWh of wind sold to the market exceeds the subsidies paid per MWh of energy generated from wind.

[22] The paper distinguishes among three cases: (i) "Domestic offsets only", which assumes that (net) electricity exports do not offset any carbon in foreign markets, (higher bound of the cost range), (ii) "Exports replace coal", which assumes that exports offset only lignite for the case of Germany and coal generation for the case of Spain, (lower bound of the cost range), and finally (iii) "Exports replace natural gas", which represents an intermediate case assuming that exports entirely replace foreign gas-fired electricity.

[23] By making driving cheaper, fuel-efficiency measures could result in users buying more and bigger cars and could in this way offset the fuel savings achieved (Vivanco et al., 2016).

The measurement of cost-effectiveness of decarbonisation support programmes may also include the impact on biodiversity and the ecosystem. Low-carbon technologies could have adverse impact on water quality (e.g. pollutants deriving from electricity generation that contaminates water) and water availability (e.g. hydropower, Carbon Capture and Storage (CCS)) (Lechón et al., 2018, Macknick et al., 2011); in this sense, Hadian et al. (2014) proposes to evaluate the overall footprint of RES considering *inter alia* water use efficiency and land use efficiency. RES can also have a negative effect on air pollution: ETC/CME[24] (2019) estimate the impact of RES technologies on the major air pollutants and show that combustion-based renewable energy technologies (e.g. biogas, biomass, bioliquids) have an increasing impact on certain emissions (e.g. nitrogen oxide (NOx) and volatile organic compound (VOC) emissions).[25] The quality of air has also been mentioned as a paramount objective for Poland's policy makers during the interviews complementing this study. The literature points out that decarbonisation pathways should be compatible with biodiversity protection, by reducing energy demand and natural resources consumption, optimise land-based carbon sequestration[26] as well by privileging energy sources that minimise negative effects on natural resources (e.g. water, land) and protect biodiversity and the ecosystem (Florin et al., 2009, Bowyer et al., 2015, Deprez et al., 2019)[27]. Florin et al. (2009) proposes, for instance, to use life-cycle assessments to analyse the environmental impact of goods and services. Although this strand of the literature mainly deals with RES and CCS technologies, the findings can be generally applied to the overall area of decarbonisation measures.

The overall environmental effects of decarbonisation support schemes also depend on innovation spillovers and positive externalities: Ghisetti and Quatraro (2017) finds that Italian regions with higher investments in green technologies have better environmental performance and that this effect derives from both investments in the same sector and in vertically related ones.[28] Corradini et al. (2014) show that investments in innovation activities positively react to environmental abatement decisions of the other sectors.[29] One of the main sources of such intersectoral spillovers are research and development results, which are only partially appropriable (Gillingham and Stock, 2018, Bollinger and Gillingham, 2019[30]). Spillovers may occur though pathways such as hiring employees of other firms, watching competitor strategies, increased efficiency of permitting by building permit offices, and more widespread adoption of best practices as are publicized by industry organizations. Another source of positive externality is the "chicken and egg" externality, according to which an expenditure today influences the options that are available to others in the future. For example, purchases of electric vehicles today will, on the margin, stimulate demand for charging stations, which once installed will lower the effective cost for future potential purchasers of electric vehicles (Gillingham and Stock, 2018).

The question of whether including spillovers and positive externalities into the measurement of cost-effectiveness is strictly interrelated to the time-horizon used to make the

[24] The ETC on Climate Change Mitigation and Energy (ETC/CME) is an international consortium working with the European Environment Agency.
[25] In particular, the study estimates the effect of RES technologies on the emission of key air pollutant emissions sulphur dioxide (SO2), nitrogen oxide (NOx), particulate matter (PM2.5 – particulate matter 2.5 micrometres or less in diameter and PM10 – particulate matter having a diameter of less than 10 micrometres) and volatile organic compounds (VOCs). It focuses on the 28 EU Member States in the period 2005-2015.
[26] Terrestrial carbon sequestration is the process through which CO_2 from the atmosphere is absorbed by trees and plants through photosynthesis and stored as carbon in soils and biomass.
[27] In this context, Deprez et al. (2019) argue that the biodiversity impact of nuclear and fossil fuels with CCS, together with solar and wind, is rather limited. Following IPBES (2019) results, the study recommends privileging non-biomass renewable energy sources other than hydropower (IPBES, 2019; CH 5, 5.3.2.4).
[28] The paper develops a cross sectoral analysis of direct and indirect effects of green technologies in Italian Regions and investigates the effects of investments in environmental innovations on environmental performances, the latter proxied by an environmental productivity measure.
[29] Corradini et al. (2014) develop an empirical analysis based on a panel dataset of EU manufacturing sectors.
[30] They assess the existence of the learning-by-doing effects in the solar photovoltaic installations in the US and find that some of the learning-by-doing effects are not appropriable and create spillovers across firms.

assessment. Under certain conditions, such as technology path dependence[31] and lock in, policy measures leading to a cost-effective GHG emissions mitigation in the short term may not allow to reach long-term emission targets at the lowest possible costs, thereby meaning that they might not be cost-effective in the long-run (Del Rio, 2008). The reason is that currently expensive technologies have a large potential of cost reductions through learning effects and research and development (R&D) investment (Del Rio, 2008) and once economies of scale are achieved (Gillingham and Stock, 2018).[32] Assuming a long-term perspective when assessing cost-effectiveness, however, would allow to support technological breakthroughs with a higher abatement cost in the short term and this not without risks. The irreversibility of investments creates the risk of being locked in a new technology that might become rapidly outdated (Florin et al, 2009).[33]

When assessing the cost-effectiveness of support measures aimed at reducing energy consumption rather than the CO_2 emission for a given level of consumption, policymakers may also use different metrics than € per abated tonne of CO_2, such as € per saved KWh or net present values of benefits and costs, see Annex 1.1.

The findings of the literature examined are specific to decarbonisation, and may not be considered applicable to other areas of environmental protection (e.g. circularity and biodiversity). Cost-effectiveness of decarbonisation schemes is generally measured in terms of EUR per tonne of abated CO_2 or CO_2 equivalent. The appraisal of the CO_2 emission reductions and the abatement costs should duly take into account the price and abatement interaction effect with overlapping decarbonisation measures. This especially applies for the RES and the EU ETS. The literature also stresses the relevance of further impacts on environmental dimensions other than CO_2 emissions reduction (e.g. biodiversity, air quality) as well as intersectoral spillovers when measuring cost-effectiveness. While the irreversibility of the investment requires some caution, a short-terms assessment of cost-effectiveness may not allow to reach long-term emission targets at the lowest possible costs.

1.2.2 The design of industrial decarbonisation schemes

Industrial decarbonisation refers to the processes required for carbon-emitting companies to contribute to GHG (e.g. CO_2) emissions reduction and encompasses different potential technology pathways, including *inter alia* CHP, CCS and other energy efficiency programmes and technologies. For each of these technologies, this section reviews how subsidy measures have been or could be designed drawing on both the European and the US experience, and how they compare with each other. As it will be discussed below, among these measures, carbon contracts for differences have recently gained increasing attention. This section does not assess, however, how the subsidy design takes into account the impact on competition as there is no literature that deals with this topic.

The 2014 EEAG define CHP as the simultaneous generation in one process of thermal energy and electrical and/or mechanical energy. If efficiently designed, CHP systems can ensure improvements in energy efficiency as opposed to conventional facilities, since they produce two forms of useful energy – heat and electricity – from a single fuel source. By extracting more useful energy from one fuel source than the combination of processes that occur at traditional power plants and separate facilities that produce heat (Kalam et

[31] Path dependencies emerge because technology choices are subsequently reinforced by positive feedback effects in technology systems, e.g., firms often choose to build on accumulated technology-specific knowledge when developing new or better-performing products and processes (Lehman et al. 2017).
[32] One of the country experts interviewed also reported that it is necessary to have long term goals to trigger innovation on the technology side.
[33] There is also a wealth of the literature which stress that delaying action in the abatement of CO_2 will increase costs in the future (see Winning et al., 2019, and Bosetti et al., 2009). Higher CO_2 concentration in the atmosphere will lead to increased climate damages, and more stringent and costly policies will have to be implemented to reach the same long-term goal (see Council of Economic Advisers, 2014). This may discourage the adoption of nascent technologies that delay the CO_2 mitigation. Nonetheless, assuming a long-term perspective should allow to take into account also these costs.

al., 2012), CHP plants allow to achieve primary energy savings of fuel. The Energy Efficiency Directive (2012/27/EU) defines high-efficiency CHP as a plant with installed capacity above 1 MWe that provides primary energy savings (PES) of at least 10% compared to two separate facilities one producing heat and another electricity. There is (limited) literature showing that CHP plants may often operate below this threshold, and even with negative PES (see Badami et al., 2014, and Comodi et al., 2016 for Italy).[34]

Member States are currently using several instruments to support CHP investments: quota system and certificates, fixed premia on top of the electricity prices - administratively set or allocated with auctions[35]- direct grants[36]. A recent study[37] commissioned by BMWi provides a comparison of these instruments, by assessing their effectiveness – i.e. the ability to meet the primary objective of the programme, that is the increase of CHP electricity production rather than an identified environmental benefit - and their cost efficiency – i.e. the ability to minimize the costs associated to the achievement of the primary objective. The report concludes that fixed premiums and auctions are the most appropriate instruments to support the development of cogeneration under the German CHP Act. The report finds that auctions ensure cost efficient funding and fixed market premiums offer incentives to invest in system-friendly CHP projects.[38]

The BMWi study compares the current German CHP support in terms of fixed premium with alternative instruments. Feed-in tariff (FIT) is considered effective and partly cost efficient: due to the lack of exposure to electricity prices signals, there is risk of over subsidising or of deadweight effects (i.e. free riding)[39], as support is granted even when the aid is not necessary. The possibility of over subsidising and free riding is not mitigated by the sliding[40] nature of the premium, as it is viewed as still largely independent of the electricity price. In this context, a fixed premium with corridor, i.e. with a floor and a cap, could both reduce the risk of over subsidising and free riding. Tax benefits and investment subsidies proved not to be effective or cost efficient in promoting electricity production from CHP plants: tax benefits provide an incentive to produce electricity only when prices are high, investment subsidies stimulate investment in capacity and not directly the production of CHP electricity, which could lead to plants being subsidised despite their low profitability. A quota system with tradable certificates is also not particularly effective, due to uncertainties about future market developments and certificate prices. Cost efficiency also cannot be guaranteed and the administrative costs for introducing and managing a quota system are significantly higher than the costs for other support instruments. Annex 1.2 provides further evidence on how the effectiveness of CHP schemes can be improved.

CCS refers to all the technologies that capture CO_2 emitted from industrial plants and prevent it from being released in the atmosphere, most commonly by injecting it in suitable underground geological formations that serve as storage. CCS technologies face market failures typical of environmental innovations, and thus of low-carbon technologies: environmental externalities are not fully internalised and the carbon price with the EU ETS is well below the level required to significantly mitigate carbon emissions, the benefits of innovations are not fully appropriable, information asymmetries and the investment's risk increase the cost of capital (Von Stechow et al., 2011). Further to the above, there is significant uncertainty about the additional costs of related to the transport, storage and

[34] The existence of CHP plants operating with negative PES depends on the relative price of the fuel used by the CHP unit compared to the price of the electricity bought from the grid. If this ratio is low (e.g. because of tax discount for the CHP fuel), operating the CHP is profitable even if it entails higher energy consumption.
[35] See Box 1 in Annex 1.2 for more details.
[36] In 2017 Denmark invested in the conversion of a coal-fired power plant into a high-efficiency CHP plant. SA.44922.
[37] The study was carried out by Fraunhofer IFAM, Öko-Institut e.V., BHKW-Consult, Stiftung Umweltenergierecht and Prognos AG in 2017.
[38] Neuhoff et al. (2017) refer to system-friendly installations as the ones that produce at times when electricity is more valuable.
[39] Deadweight effects refer to the case in which aid is granted to projects that would have been implemented even in the absence of financial support.
[40] In addition, according to the report, neither FITs nor sliding premiums directly address the secondary objective of the CHP Act, namely primary energy saving and CO_2 emissions reduction.

capture process[41] (Von Stechow et al., 2011). Such uncertainty is further magnified by the long lead time of CCS power plants, which could lead to the technology valley of death (Murphy et al., 2003). Hence, the literature points towards instruments that could foster CCS investments by overcoming such uncertainties. Von Stechow et al. (2011) provide a multi-criteria analysis[42] of CCS support instruments, mainly drawing on the German and the UK[43] experience. They conclude that bonuses, i.e. a premium on top of the electricity price, and CO_2 price guarantees or carbon contract for differences, are the most effective instruments at diverting investments from conventional fossil fuel plants to CCS plants, minimising the risks of other side effects. The major drawbacks of the remaining analysed instruments are as follows. A mandate or emission performance standard (EPS)[44] could positively trigger CCS investments but, given that alternative investments in other low-carbon technologies (such as RES and nuclear plants), involve less uncertainty, complementary incentives are needed to accelerate the investments in CCS. Grants and tax breaks provide upfront payments and reduces the investors' uncertainty, but they might hinder incentives to minimise overall lifecycle costs and dry out the public budget for green technologies. A quota system[45] might not be effective in overcoming uncertainty, as investors would be exposed to both the prices fluctuations of certificates and electricity; on the other hand, while a FIT[46] system could effectively address uncertainties, it decouples the support from short-term price signals in the electricity market[47]. The paper also stresses that FIT systems may also advantage beneficiaries by encouraging them to feed power to the grid even in case of low electricity prices and high supply: un-subsidies plants would have instead to reduce or halt their production to avoid too low, or even negative, marginal revenues. This finding generally applies to FIT for decarbonisation support, regardless of the specific technology being aided.

Carbon Contracts for Differences (CCfDs), which are further defined in Section 2.4.3 (study item 2), have recently played a major role in the discussion on the most appropriate policy options to promote investments in low-carbon technologies, including low-carbon production processes for basic industrial materials such as steel or cement. CCfDs help investors hedging against CO_2 prices volatility, by offering them a fixed carbon price. Sartor et al. (2019) confirms that EU ETS prices are still too low and too volatile to support the development of low-carbon basic materials and allow them to compete with cheaper high carbon alternatives.[48] Richstein (2017) adds that low prices are not successful in contributing to bridging the valley of death: this concerns projects in capital-intensive sectors, which often do not have enough capital to leave the pilot phase and to be further carried out. According to Richstein (2017), CCfDs could help reducing financing costs, as emission reductions projects are not mature enough to be financed through ETS but still go beyond the scale of R&D funding. The price of the carbon contracts could either be determined by the policy maker or in a tender (Richstein, 2017).

Finally, as for the design of **energy efficiency programmes**, Thollander et al. (2007) and Stenqvist et al. (2011) evaluate two Swedish energy efficiency programmes in energy-

[41] The additional costs are: (i) additional fuel costs to run the capture process, (ii) installation of the transport and capture equipment, (iii) the storage of CO_2, including injection, monitoring, liability, and (iv) regulatory uncertainties with respect to security, leakage, environmental impacts of transporting and storing CO_2.
[42] Support schemes are evaluated with respect to: (i) reducing investment uncertainty; (ii) limiting electricity market impacts; and (iii) limiting low-carbon investment impacts.
[43] Germany has experienced the use of capital grants and FIT. The UK has experienced the use of capital grants and quota obligations.
[44] CCS could be made mandatory. The EPS sets a cap on the emissions from specific plants, e.g. 500 g CO_2/kWh on coal plants.
[45] Utilities are required to source a certain percentage of their electricity from low-carbon technologies.
[46] Feed-in tariffs can be either fixed (FIT) or can be based on a fixed or sliding premium (FIP). FIT envisages a fixed amount of support to be granted per kWh of energy produced, while fixed premiums provide an additional amount on top of the electricity price (Del Rio (2012)). This could be granted in the form of a sliding premium, meaning, i.e. the difference between a predetermined reference tariff and the electricity price.
[47] This is further considered in Section 2.4.3 (study item 2).
[48] Sartor et al. (2019) specifies that the current level of EU ETS prices, i.e. €30/tCO_2, is too low and should reach €50-100/tCO_2 to successfully incentivize the development of low-carbon technologies. The paper also stresses that during its 15-year history, the EU ETS carbon price has fluctuated between 0€/tCO_2 and ~30€/tCO_2.

intensive industries, namely Highland and the Swedish Programme for improving energy efficiency in energy intensive industries (PFE). While Highland was based on energy audits to small- and medium-sized (SME) manufacturing industries in Sweden, PFE was providing tax discounts to the Swedish firms that would fulfil specific efficiency requirements. The cost-effectiveness of both programmes is measured in terms of public and private costs for energy saved (Thollander et al., 2007). While results in terms of private money spent – i.e. investment costs at the firm – in relation to energy saved is approximately the same for both programmes (Highland with 7.5 kWh/€ and PFE with 5.8 kWh/€), Highland appears to be more effective in terms of saved electricity per € of public money invested in the programme, i.e. subsidy and administration costs (Highland with 125 kWh/€ and PFE with 11 kWh/€). Stenqvist et al. (2011) assesses the impact of PFE and considers, in addition to energy savings and efficiency improvements (i.e. gross impact), free riders, spillover effects and double counting effects[49] (i.e. net impact). While the gross annual impact implies a unit cost of 6.5 €/MWh, the net annual impact, ranges from a 9.3 to 13.6 €/MWh of saved electricity, depending mostly on the presence of free riders.[50]

The literature review on the design of industrial decarbonisation schemes describes different instruments to support low CO_2 emitting technologies (e.g. CHP, CCS, energy efficiency programmes). Evidence from the Member States suggests that, when promoting CHP, fixed premium and tenders are the most appropriate instruments; while CO_2 price guarantees and CCfDs can effectively overcome the uncertainties related to CCS investments. On the other hand, tax deductions, grants, and quota systems are typically perceived neither effective or cost efficient to promote CCS and CHP. CCfDs are playing an increasing role in promoting low carbon technologies in both the energy and industrial sector: by reducing financing costs, CCfDs may enhance investments in capital intensive sectors, for which neither the ETS pricing nor the R&D funding are feasible.

1.2.3 Competitive bidding as a means of granting aid

Following the 2014 revision of the EEAG, state aid for RES-E must be granted through a competitive bidding procedure.[51] The rationale is that auctions should lead to the minimisation of support cost by having several stakeholders compete for support. There is a consistent literature confirming that auctions in the energy sector lead to a reduction of support over time (Cozzi, 2012, Lieblang, 2018, AURES, 2016b).[52] Del Rio et al. (2014), Cassetta et al. (2017) and Eberhard (2014) also find that auctions can lead to lower support, when compared to other schemes (e.g. FITs).

How auctions minimise support cost is however dependent on their design. Auctions may lead to rent seeking (Latacz-Lohmann et al., 2005), collusion (Klemperer, 2002), and entry deterrence (Mora et al., 2017), which all inflate the bids. Auctions may also lead to under-

[49] The study defines free riders as the companies that would have saved energy even without PFE and spillover effects as the savings that are indirectly caused by the programme in addition to what was targeted. Double counting involves potential overlapping effects between different policies.
[50] The analysis of spillovers show that programme had an impact on heat and fuel savings as well, thereby enhancing the environmental benefits of the programme. The risk of double counting the effects of PFE is instead very low, as there are no other policy instruments that specifically requires electricity saving measures to be identified, implemented, monitored, and reported as PFE.
[51] 2014 EEAG, §127: Aid may be granted without a competitive bidding process as described in paragraph (126) to installations with an installed electricity capacity of less than 1 MW, or demonstration projects, except for electricity from wind energy, for installations with an installed electricity capacity of up to 6 MW or 6 generation units.
[52] Cozzi (2012) provides evidence that under the NFFO (Non-Fossil Fuel Obligation: introduced by the Electricity Act 1989, it consisted of five auctions calling for bids for Power Purchase Agreements to produce electricity from non-fossil sources; it was substituted by a quota system with the Utilities Act 2000) in UK the price of electricity from renewables dropped significantly, particularly for onshore wind (from 10p/kWh in NFFO1 to 2.88 p/kWh in NFFO5) (similar results hold for Brazil and China). Similar conclusions are reached by Lieblang (2018) in Germany (who analyses the results of the tenders for onshore wind under the EEG revision) and AURES (2016b) who analyse auctions for RES in 8 EU countries and 4 non-EU countries: each country reported efficiency gains, either over time or when compared to previous support schemes, with results in California, Brazil and South Africa being remarkable (average contract prices across all utilities in California fell from €79.5/MWh in the first round to €70.5/MWh in the third one, in Brazil the average final price was €54/MWh, about 60% lower than under Proinfa – the previous FIT programme).

bidding and low realisation rates when, due to the lack of information, bidders underestimate technological cost or cost of the aided measure ("winner's curse" phenomenon) (AURES, 2015, AURES, 2016a, AURES, 2016b). This section reviews under which conditions the tender can be expected to be sufficiently competitive to lead to cost discovery and guarantee the proportionality of the aid. Special attention will also be devoted to the possible scoring approaches in multi-criteria auctions and to the comparison of technology-neutral and -specific tenders. The review mainly draws its conclusions from the existing papers on RES auctions and energy efficiency auctions, but it also relies on the general auction literature and on the papers on auctions for conservation programmes (see Annex 1.3.2). The findings of this section are generally applicable to any auction scheme, and therefore can be extended to all the areas of environmental protection.

Auctions' design concerns several elements. First there is the *pricing rule*. The two most common rules are *uniform pricing* (or pay-as-clear) and *discriminative* (or pay-as-bid). In uniform pricing auctions, all successful bidders earn the cut-off price, either the highest accepted or the lowest rejected bid, with bids determining only the chance of winning. In pay-as-bid auctions, winners are paid the price they bid. Thus, the dominant strategy for bidders in uniform pricing auction is to bid their true opportunity cost (Latacz-Lohmann et al., 2005, Burtraw et al., 2010). The discriminative pricing rule has the advantage that it offers bidders no more than their bid, and so it has found high public acceptance (AURES 2016b). Both pricing rules have some drawbacks. Uniform pricing can lead to the winner's curse for inexperienced bidders, as they might submit offers below what is financially sustainable to make sure they are awarded some capacity (Gephart et al., 2017, AURES, 2016a). With discriminative pricing, bids will depend on participants' expectations about competitors' behaviour, and bidders may be tempted to manipulate their bid by guessing the highest acceptable bid to secure a rent[53] (Friedman, 1960, Gephart et al., 2017 and Latacz-Lohmann et al., 2005)[54]. Both AURES (2016b) and AURES II case studies show that pay-as-bid has been the preferred pricing rule in most EU and non-EU countries in RES auctions.[55] Nonetheless, Akbari-Dibavar et al. (2017) argue that uniform pricing is preferable because it is conducive to innovation and improved efficiency, as it rewards the most efficient players. A reserve price can help smoothing the downsides of the discriminative pricing rule and avoiding rent seeking (AURES, 2015, AURES, 2016a). Rego (2013), however, points out that if the reserve price is too low no bids will be received, while if it is too high bidders will seek a rent[56]. Moreover, if the reserve price is not disclosed the risk is that many bids will be excluded from the auction as they exceed the reserve price, leading to a shortage of supply. Conversely, if it is disclosed and competition is low, auction participants are likely to bid close to the reserve price (Gephart et al., 2017)[57].

The *auction format* plays an important role in its outcome. The auction can be sealed bid, dynamic, or a hybrid of the two. In sealed bid auctions, all bidders simultaneously submit a schedule of prices and quantities that they are willing to supply, without any knowledge of the other participants' strategy. In dynamic (or clock) auction, bidders can update their bids over time: the auction entails various "clock stages" showing the most recent bid price, and bids are then adjusted until there is no excess of supply (AURES, 2015). While sealed bid auctions reduce the possibility of collusion among bidders caused by signalling (Gephart et al., 2017, Cramton, 2013), they prevent participants from acquiring information on the price of the product and so can lead to the winner's curse (AURES, 2015). Hybrid (or Anglo/Dutch) is an alternative which combines the two formats. First there is a

[53] Conversely, Xiong et al. (2004) find that in a setting of repeated auctions with bidders' learning and limited actors, prices under pay-as-bid are lower than under uniform pricing, as bidders tend to bid closer to the market clearing price and thus the supply curve is more flattened, assuming a perfectly inelastic demand curve.

[54] The principle of cost discovery in uniform pricing versus discriminant pricing holds generally, not just for RES. See Ward et al. (2007) for an example on conservation contracts.

[55] Of the 13 countries studied in AURES II (AURES II case studies) (Argentina, Canada, Chile, Denmark, Germany, Greece, Hungary, Mexico, Netherlands, Poland, Portugal, U.K., Ukraine), 11 use pay-as-bid as a pricing rule, the U.K. uses uniform pricing and Germany uses uniform pricing only for community energy projects.

[56] Similar reasonings are presented also in AURES (2015), Gephart et al. (2017), and in AURES (2016a).

[57] Latacz-Lohmann et al. (1997) and Claassen et al. (2008) claim that to avoid strategic bidding, a degree of uncertainty about the reserve price should be maintained.

clock phase, when bidders can update their bid and provisional winners are identified, then a sealed bid phase is implemented, where the bid can be no higher than the price identified in the clock stage. The first phase allows for price discovery, while the second phase prevents collusion and favours price minimization, as the finalists are in a highly competitive environment (Del Rio et al., 2014, Klemperer, 2002, and Moreno et al. 2010).[58] Brazil has successfully applied this format for electricity procurement (Rego, 2013).

The design of auctions may also include *prequalification criteria, penalties, deadlines*[59], which can reduce underbidding and improve realisation rates. Prequalification criteria and penalties have been used in Italy, South Africa, and California, leading to high realization rates (Cassetta et al., 2017, AURES, 2016b[60], Eberhard, 2014). According to AURES (2016b), case studies show that prequalification have been more effective than penalties in providing high realisation rates (also Mora et al., 2017), mostly because prequalification criteria can include building permits and grid-connection permits, which are among the most common problems faced by new installations for energy generation or for CO_2 reducing technologies. Gephart et al. (2017) stresses the importance of keeping qualification requirements as well as penalties at a reasonable level to improve the level of competition in an auction. Despite the common concern that prequalification criteria may hinder competition, Cassetta et al. (2017) and AURES (2016a) argue that they do not lead to reduced competition, either because they do not act as a barrier to entry, or because they induce stronger bidders to participate.

Rather than using multiple criteria to qualify for participation, they can be used to evaluate bids. While price-only auctions have been the most common method of bid evaluation in most Member States, multi-criteria have been used, among others, in South Africa, China, California, France and Portugal (Eberhard, 2014, Mora et al. 2017). Price-only auctions may lead to market failures when they do not allow to capture the contribution to environmental objectives and the externalities that could accrue from the measures being aided (e.g. abatement of CO_2 emissions, security of supply). In this sense, the attempt of Member States of shifting to criterion like €/tCO_2 avoided could help identify and prioritise projects that deliver environmental protection at lower cost and avoid subsidies for projects that are less worthwhile. Public agencies may also revert to multi-criteria auctions to include *inter alia* their preferences for: experienced developers, sound financial and technical backing, nurturing promising new technologies, promoting small players, projects that minimise environmental impacts[61], and increasing social acceptance.[62] The case for taking factors other than price into account is helpful when bidder have substantially different approaches, which are apt to lead to projects that differ with respect to a variety of social objectives (Ausubel et al. 2011c).[63] The main drawback of multi-criteria auctions is

[58] For the hybrid auctions to lead to cost discovery, Cramton (2013) and Ausubel et al. (2011a/2011b) propose the use of Vickrey-nearest-core pricing (a pricing rule in which winners are paid the first non-awarded bid, subject to the constraint that no combination of other bids would lead to a better financial outcome), and an activity rule based on revealed preferences (if an actor decreases the quantity bid, in the successive stages of the clock phase she cannot increase it above the previous level). As the second phase produces uncertainty on the winner, this leads to increased participation (Klemperer, 2002).

[59] Prequalification criteria can be material (e.g. construction permits) or financial (e.g. bid bonds) (Gephart et al., 2017, AURES, 2016a). Penalties need a deadline for the realization of the project. Del Rio et al. (2014) stress that longer deadline may induce overoptimism and uncertainty, while short deadline increases investors' risks and may put upward pressure on bids. Overoptimism has also been noted by Huebler et al. (2017).

[60] AURES (2016b): "At least 75% of projects … in California and South Africa have been built".

[61] See for instance the French RES tenders for installations larger than 250kW called in 2013, where one of the criteria was the reduction of the pollutants released in the cooling water system by solar energy, or the minimisation of the negative impact on different species and habitats.

[62] For instance, in South Africa local content development counted for 30% of the total score given to a bid, while in France for installations larger than 250kW environmental impact and contribution to R&D weighted more than the price (Eberhard, 2014, AURES, 2015).

[63] According to Ausubel et al. (2011b), in most cases multicriteria can be replaced by prequalification criteria. Although, when interested in state-specific goals, multicriteria auctions are better suited.

that they tend to be highly subjective and may hinder the achievement of efficient outcomes.[64] When comparing alternative technologies for reducing CO_2 emissions, public authorities may have limited information of the trade-offs across the several objectives they aim to achieve and may not perfectly express them in the scoring rule (Ausubel et al. 2011c). Furthermore, each objective can be measured along several dimensions. Ausubel et al. (2011c) stress that the criteria selected to give bidders a discount should be documented ahead of time (transparent), must require objective evaluation (objective), should have a clear "yes" or "no" answer" (simple) and verifiable. The criteria should also be verifiable from the start, to avoid subjective decisions and possible legal disputes (AURES 2015, Ausubel et al. 2011b).[65]

Ausubel et al. (2011c), propose several formats for multi-criteria auctions for offshore wind projects in the U.S. The paper suggests that it is best to accommodate additional selection criteria in a manner that allows for price-only auctions: for example, by giving bid discounts to bidders that satisfy certain qualification factors. This would help to achieve the transparency of the selection process and preserve or enhance efficiency. When multiple factors are aggregated into a score (scoring auction), bidders have the incentive to choose the technical characteristics of their bid to maximize their technical score and adjust their financial bid accordingly. This leads to efficient outcomes only if the technical portion of the scoring rule accurately reflect the trade-offs inherent in the service being provided. Annex 1.3 provides further evidence on how to implement multi-criteria auctions, also based on the conservation programme literature. Interestingly, the latter suggests that the costs savings accruing to the price-discriminant auctions may arise primarily from the ability to assess and prioritise beneficiaries through a cost and benefit criterion, rather than from the bidding procedure.

Fostering participation is paramount in auctions. AURES (2015) and Gephart et al. (2017) identify one of the main conditions to enhance competition in the "scarcity requirement", i.e. that the volume auctioned must be below the capacity of participants to ensure the excess of supply; Buckman et al. (2019) and AURES (2015), argue that the high administrative costs to participate in an auction lead to the exclusion of small- and medium-sized plants, reducing actor diversity and therefore competition (also Lieblang, 2018)[66]; frequency of rounds is also a problem with auctions, as stop-and-go cycles increase uncertainty and the cost of financing, reducing competition and possibly leading to lower cost-effectiveness (Cassetta et al., 2017, Butler et al., 2008).[67]

Broadening the auction to multiple technologies, rather than focusing on specific technology, can be a way to stimulate competition.[68] The academic research discusses the trade-off between "technology-neutral" and "technology-specific" auctions. Lehmann and Söderholm (2017) define technology-neutral policies as policy options pricing environmental externalities (e.g. by emissions taxes) or generic subsidies to R&D and/or technology deployment.[69] In contrast, technology specific policy approaches promote selected technological fields, sectors or even projects based on differentiated support levels. Technology-neutral auctions, by enhancing competition between technologies, can improve the support cost-effectiveness in the short term[70]. However, if policy makers correctly identify

[64] Ausubel et al. (2011c): "*The case for taking factors other than price into account is especially great when the parties have substantially different approaches, which are apt to lead to projects that differ with respect to a variety of social objectives*".
[65] In South Africa the Department of Energy holds a conference at the start of the auction, for bidders to understand the different criteria.
[66] This issue has also been raised during the stakeholders' interviews complementing the case study.
[67] The need for auction schedules to reduce investors risk and boost participation has also been noted by Del Rio et al. (2014) and AURES (2016b).
[68] Mora et al. (2017) notes that most countries in the AURES project used technology-specific auctions.
[69] These are different than multi-technology tenders, where competition is generally limited to two technologies (e.g. solar PV and wind), rather than to being open to all the available technologies. Sometimes, however, technology-neutral tenders may also envisage some eligibility requirements that restrict their neutrality.
[70] Although the literature is focused on technology-neutral tenders, this result also applies to multi-technology tenders. For further details, see section 1.2.4.

technologies with long-term potential, technology-specific auctions promote the deployment of less mature technologies and foster technology diversity.[71] This is especially relevant for measures supporting RES, whose contribution to the grid is not constant over time: allowing a mix of different technologies will provide back-up energy during peak load hours by exploiting the complementarity in the intermittence across technologies, and improve the security of supply.[72] Technology-specific auctions may however lead to market segmentation which lowers competition and potentially induce collusive behaviour and strategic bidding (Mora et al. 2017, Del Rio et al. 2014). Another common critique raised against technology-specific auctions is that, due to the lack of proper information on the technology costs and risks, a regulator may fail to design efficient schemes. In this respect, technology-neutral schemes may be superior because they require fewer policy design decisions (Lehmann and Söderholm, 2017).

De Mello Santana (2016) stress that technology-neutral schemes will trade-off static efficiency for dynamic-efficiency: if the currently least-cost technologies are selected, immature technologies are not developed, and their costs are not brought down through learning-by-doing, creating a lock in of incumbent technologies (the "paradox" of the technology-neutral policies). This result is in line with Fais et al. (2014) who find that the choice of the least-cost technology does not entail a lower level of the support, as it can translate in windfall profits for producers rather than in incentives to develop immature technologies.

Gawel et al. (2017) and Lehmann and Söderholm (2017) stress that the promotion of technology-neutral RES-E support schemes rests on the assumption that the costs of renewables deployment beyond the private generation costs—e.g. system integration costs and environmental costs—are irrelevant for RES-E policy design because they are either homogenous across RES-E technologies or internalised by other policies. This is hardly the case: uncertainty on the investment returns, the presence of knowledge spillovers, technological market failures (which take place when the market ignores technology-specific learning effects) will lead producers to focus on existing technology and to underinvestment in RES-E technologies with great long-term potentials for cost reductions. This effect may be reinforced by the presence of path dependencies. Environmental and system integration costs are clearly heterogeneous among different technologies[73], and need a degree of technology differentiation to be properly internalized. Unless the policymaker is able to design a scheme addressing all these issues, which is complicated given the information asymmetries between the government and the producers, technology-neutrality may not be able to minimise costs in the long run. These problems might be solved with supports that discriminate across technologies with different costs, as recently proposed for the UK contracts for differences scheme for renewable energy generation (see Annex 1.3). However, this is still dependent on policymakers identifying the "right" technologies to specifically promote.

Competitive bidding has been used to grant support also for energy efficiency measures in Switzerland (Radgen et al., 2017), Portugal (Apolinário et al., 2012, Sousa et al., 2018), and in Germany (Ifeu and Prognos, 2019). These are generally sealed bid auctions with pay-as-bid pricing rule. Bids are ranked according to the cost per energy saved (€/MWh avoided) – e.g. in Germany - or in a multi-criteria auctions – e.g. in Portugal. The support is generally limited to a percentage of the investment costs. Results of ex-post evaluation studies show that most of these auctions have exceeded expectations both in terms of costs saved and electricity avoided. More details are provided in Annex 1.3.

[71] One of the country experts interviewed stated that one quite explicit goal of the technology-specific auctions is to make sure that a particular technology is in the market.
[72] For example, if mainly PV plants are awarded support over a longer period of time, the auction scheme could make a smaller contribution to serving the load peaks (in the evenings and in winter) (Navigant et al. (2019)).
[73] E.g.: landscape impacts are higher for wind power than for solar PV and biomass, system integrations costs are higher for intermittent RES-E technologies.

A wide literature shows that auctions can minimise the cost of support and this can depend on their design, namely the pricing rule (pay-as-bid vs pay-as-clear), the format (static, dynamic or hybrid), the existence of prequalification criteria. While pay-as-clear auctions could lead to the winner's curse for inexperienced bidders, participants to pay-as-bid auction could have an incentive to manipulate their bid to secure a rent. Evidence shows that pay-as-bid has been the preferred pricing rule in most EU and non-EU countries in RES auctions. Other than in terms of pricing rule, auctions can be different in terms of format: the literature shows that while sealed bid auctions reduce the possibility of collusion among bidders caused by signalling, they prevent participants from acquiring information on the price of the product, leading to the winner's curse. The review also provides evidence on multi-criteria auctions, that could lead to inefficient outcomes when tendering authorities do not perfectly express the trade-off across the several objectives in the scoring rule. Findings on broadening auctions to multiple technologies prove that while technology-neutral auctions spur competition, they lock out immature technologies whose costs may be reduced through learning-by-doing and may lead to windfall profits for the least costly technologies. While these findings are mainly based on RES auctions, they can be extended to any auction scheme.

1.2.4 Benefits and challenges of multi-sectors schemes for decarbonisation

Broadening environmental protection and decarbonisation schemes to multiple technologies and/or multiple industrial sectors which could achieve similar environmental benefits may stimulate competition, minimise the cost of support and limit distortions as much as possible. To help the Commission to evaluate to what extent the broadening option should be pursued, this section describes the results of multi-technology schemes for RES-E support and multi-sector schemes for decarbonisation which have been implemented by the Member States in the last decade.[74] While technology-specific schemes are those dedicated to a single and specific technology, multi-technology schemes enable the participation to two or more specific technologies (e.g. PV solar and wind) or sectors (RES and industrial decarbonisation). There is a distinction between multi-technology schemes and technology-neutral schemes (which have been discussed in section 1.2.3): while multi-technology scheme promote the deployment of selected and multiple technologies or sectors, technology-neutral schemes are open to all available technologies and do not envisage any negative nor positive technology-specific discriminatory rule.[75] In both case, multiple technologies and sectors compete under the same budget. The findings of this section are based on ex-post evaluation studies requested by the tendering authorities (mainly) or independently undertaken by research centres (e.g. AURES II[76]).

Based on the evidence collected, this section proposes the following categorisation:

- multi-technology schemes for the deployment of RES-E (i.e. RES-E tenders in Denmark, Germany, France and Swedish tradable green certificate (TGC) programme);
- multi-sector schemes targeted at the reduction of GHG emissions, which include RES technologies (including RES-E, RES-T and RES-H) and CO_2 reducing technologies (i.e. the Swedish *Klimatklivet,* and the Dutch SDE+ and SDE++);
- multi-sector schemes mainly targeted at energy efficiency consumption and energy saving technologies in the industry (i.e. the Dutch Energy Investment Allowance (EIA), the German Market Incentive Programme (MAP), Energy Efficiency Fund and STEP up!).

Since the adoption of the 2014 EEAG, which introduced competitive bidding procedure to allocate RES support, tendering authorities have relied on technology-specific auctions (e.g. solar PV only) and multi-technology auctions (e.g. solar PV and wind) for RES-E support. Multi-technology auctions proved to lead to oversubscription and to reduce the cost of support. Similar to the simulation analysis in section 1.3, a French report (Artelys,

[74] Further details on the functioning of the schemes are provided in the attached Excel spreadsheet titled "List of schemes identified in the literature review – Study item 1".
[75] This is based on Jerrentrup et al. (2019).
[76] AURES II, which follows AURES, is a European research project aimed at ensuring the effective implementation of auctions for Renewable Energy Sources (RES) in EU Member States.

2020) simulates the outcome that could have been achieved by relying on a multi-technology rather than on several technology-specific tenders. The report points out that multi-technology schemes lock out more expensive technologies (e.g. hydro and biomass) and small players. While this reduces the cost of support, it negatively affects technology and actor diversity which may come with longer term costs.

A study by AURES II provides an overview of the status of renewable auctions in Germany under the 2017 EEG[77]: evaluated auctions are technology-specific (i.e. onshore and offshore wind, solar PV, biomass) and multi-technology (i.e. solar PV and onshore wind together).[78] Results show that technology-specific auctions for solar PV were successful, as both oversubscribed and with high realisation rates. Average solar PV winning bids decreased by 47% from 2015 and 2019, proving solar PV auctions were able to decrease the cost of the support. Wind auctions were not as successful: after the first three rounds with high participation and steep declining prices, the following phases have been undersubscribed. The study does not provide a measure of cost-effectiveness but rather a measure of static efficiency.[79] Multi-technology auctions stimulated a healthy level of competition and resulted in bid prices well below the ceiling price: however, solar PV installations were the only winning projects and constituted most of the bids in each round.

AURES II (2019) analysed also the Danish RES-E auctions starting from 2016.[80] Auctions were technology-specific for solar PV and offshore wind, while multi-technology auctions were launched for nearshore wind, offshore wind and solar PV.[81] The report assesses the auction outcomes in terms of weighted average support required by the winning projects - i.e. DKK/kWh - and finds that the cost of support is much lower with multi-technology auctions: for instance, the average price premium of the multi-technology winning bids in 2019 was 0.0154 DKK/kWh,[82] while the average winning bid for technology-specific solar PV installations lower than 1 MW was 0.1297 DKK/kWh[83]. Although the limitation on the size of the projects may increase the cost per unit of energy produced for the technology-specific auction, the study points out that the great disparities in terms of fixed premiums reached by the technology-specific and multi-technology auctions might depend on the level of competition: oversubscription was in fact higher in the multi-technology auctions than in the small scale solar PV auctions.

Artelys (2020)[84] evaluates the results of French RES-E tenders launched between 2016 and 2020.[85] Technology-specific tenders were carried out for ground-mounted solar, solar on building, onshore wind, biomass, and hydroelectricity installations, while multi-technology tenders were launched for ground-mounted solar and onshore wind. The study proposes to measure the cost-effectiveness of the scheme in terms of the cost for the government (€ of aid) per tonne of CO_2 abated (€/tCO_2). Results show that, in 2017, ground-based solar and onshore wind power had the lowest costs for the government in terms of avoided emissions, with 49.7 €/tCO_2 and 53 €/tCO_2 respectively; on the other hand, biomass and hydroelectricity were the most costly technologies, with 182.1 €/tCO_2 and 163.1 €/tCO_2. The multi technology tender, which awarded support only to solar installations, resulted in 34€/tCO_2 instead. In addition, the report shows that the adoption of competitive bidding procedure has not affected the concentration (based on the HHI) in the RES

[77] The EEG replaced the administratively set FITs with sliding FIPs and introduced auctions for solar PV, onshore wind, offshore wind and biomass. Case SA.38632 EEG 2014 envisaged *inter alia* a transition to an auction system starting from 2017.
[78] The study also describes the technology-neutral innovation auctions, envisaged by the revised EEG 2017. No auction round has been held at the time of writing, hence they are not part of the evaluation. The innovation auctions aim at increasing system-friendliness of RES plants and will cover several sectors (including CCS).
[79] This is measured in terms of the weighted average price of successful bids compared to the ceiling price or the weighted average price of successful bids compared to prices before the introduction of auctions.
[80] SA.44626, SA.49918, SA.45974.
[81] Offshore wind auctions were single-item and granted a sliding FIP, while solar PV's and multi-technology auctions provided a fixed FIP.
[82] This is approximately 2.1€/MWh. In 2018, the average winning bid was 0.0228 DKK/kWh (around 3.1€/MWh).
[83] This is approximately 17.4€/MWh.
[84] SA.46698, SA.46259, SA.46552, SA.47753, SA.48066, SA.48238.
[85] Beneficiaries below 500 kW received a fixed-price contract, while the bigger plants obtained a sliding FIP.

market[86] or hampered the entry of new companies. The study simulates then the impact of multi-technology tenders: candidates for actual tenders[87] are grouped in chronological order into four multi-technology (MT) periods according to the date on which bids were submitted. It is assumed that participants would have presented the same applications to the calls for MT tenders as well as to calls for specific tenders. Results show that winning technologies in the MT tender would have been mainly ground-based solar and onshore wind power, while all hydropower projects would have been eliminated due to their excessively high tariff. The MT tenders would avoid 5.6 MtCO_2/year, i.e. an average of 0.43 tCO_2/MWh per renewable energy produced. The average cost of avoided emission is €51.7/tCO_2, significantly lower compared to the 2017 estimates of cost/abated CO_2 of technology-specific tenders.[88] Artelys (2020) also concludes that MT tenders favour large projects (i.e. big players) and restrict the technologies used.

The Swedish experience with a trade certificate market for RES-E technologies shows that multi-technology schemes without controls on inframarginal rents may lead to excess profits for cheaper technologies. Bergek et al. (2010) analyses the outcome between 2003 and 2008 of the Swedish tradable green certificate (TGC) programme, whereby RES-E producers received a certificate for each MWh of renewable energy they generated, that power suppliers and certain power customers were obliged to purchase in a multi-technology certificates market, where different eligible renewable electricity sources could directly compete. Results show that (i) most of the subsidy recipients were firms that could have profitably invested without the extra payments provided via the certificate market (i.e. free riders), (ii) some firms were overcompensated when more expensive RES technologies were introduced in the system, i.e. technologies with lower costs received an extra profit.[89] The study does not suggest a measure of cost-effectiveness but finds that quota obligation fees, administrative and transaction costs, have been substantially higher than expected.[90]

Recently, Member States have moved towards the adoption of subsidy schemes broadened not only to multiple technologies but also to multiple sectors. These are integrated schemes that encompass multiple RES sectors (i.e. RES-E, RES-H, RES-T), industrial electrification and decarbonisation technologies (e.g. CHP, CCS) and energy efficiency programmes, which are all competing for a common budget. While the Dutch scheme SDE+[91] shows that broader schemes may deliver cost savings, the Swedish scheme *Klimatklivet*[92] proved that it may be difficult to identify a method to fairly compare the costs and the environmental benefits of each technology and sector (though it is important to remember that comparing projects on the basis of €/kWh is unlikely to fairly compare these projects on the basis of their environmental benefits). The early findings of the newly introduced Dutch scheme SDE++[93] also show that eligibility requirements should be carefully designed so as to include all cost-effective options for which part of the investment is unviable.

WSP (2017) and the Swedish National Audit Office (Riskrevisionen (2019)) reviewed the results of the aid programme *Klimatklivet* over the period 2015-2017. The scheme has been introduced in 2015 to support local climate investment. It supports projects in a variety of sectors, including *inter alia* energy conversion, renewable district heating and

[86] In particular, Artelys (2020) discusses the impact of the aid on competition in the electricity market, defined as production, wholesale and retail market.
[87] The simulation excludes biomass, as tenders are likely not to be repeated.
[88] For each technology, the study also calculates the cost to the State of a project over a reference year, divided by the total production. Results show for the year 2017, photovoltaics will cost the State 3.01 €/MWh more than wind power for the same tariff offered by the candidates. If this selection criteria were adopted, winning wind power would increase by 145 MW (6% more) to the detriment of solar power over all periods.
[89] The overall marginal cost curve for RES consists of several different curves, one for each technology: at each point in time, the certificate price will correspond to the most expensive technology (i.e. the marginal technology) included in the system.
[90] The additional consumer cost per kWh of electricity used (i.e. the amount shown on the electricity bill) increased from 0.02 SEK/kWh in 2003 to 0.05 SEK/kWh in 2008.
[91] SA.34411 SDE + - NL.
[92] SA.49001 Climate Leap (Stöd till lokala klimatinvesteringar).
[93] SA.53525 SDE++ scheme for greenhouse gas reduction projects, including renewable energy.

energy efficiency projects. *Klimatklivet* provides a direct grant according to a "climate benefit" ratio – equal to the amount of emission reductions per invested Swedish krona - whereby projects with a ratio above a certain breaking point receive support.[94] Both studies criticize the measure. WSP (2017) finds that in light of the variety of eligible projects, it is difficult to identify a single methodology that allows to calculate both emission and cost reductions in a fair way and that ensures to prioritise the more cost-effective technology.[95] The study measures the cost-effectiveness in terms of both investment cost and aid per avoided CO_2 equivalent emissions (SEK/kgCO_2e). While biogas refuelling stations are among the less costly technologies with an average investment cost and granted aid of 0.41 SEK/kgCO_2e and 0.19 SEK/kgCO_2e respectively; the cost per avoided emission of energy efficiency measures is three times higher, with an average of 1.28 SEK/kgCO_2we of investment and 0.58 SEK/kgCO_2e of aid. Riskrevisionen (2019) concludes then that the climate goals could have been achieved at a lower marginal cost: the study identifies in fact several inaccuracies in the calculation of emission reductions underlying the measure of cost-effectiveness, including for instance the potential effect on emission due to the interaction with other policy instruments (see Box 3 in Annex 1.4.2).

The Netherlands experience provides an insightful example of the benefits and challenges of an auction scheme broadened to multiple technologies for both RES-E and RES-H (SDE+) and an integrated auction scheme for both renewables and industrial decarbonisation technologies (SDE++).

In a study commissioned by the Dutch Ministry of Economic Affairs, CE Delft and SEO Economisch Onderzoek (CE and SEO (2016)) examine the multi-sector SDE+ scheme over the period 2011-2015. Eligible technologies are biomass, hydro, solar photovoltaics, solar thermal, geothermal and onshore wind for both electricity and heat generation. SDE+ provides support in the form of sliding FIP determined through multi-technology multi-round auctions, in which all technologies compete under an overall budget ceiling, that is split in allocation phases. Compared to the previous SDE scheme, SDE+ does not include budget ceilings for each technology but does include technology-specific bid caps (ceiling prices). Due to budget exhaustion, more expensive techniques are less likely to be subsidised, although the free category[96] can partially alleviate the problem. Box 2 in Annex 1.4 provides further details.

The openness to multiple RES technologies has generally been perceived as a major plus of SDE+, leading to significant price reductions and thereby a more cost-effective policy.[97] CE and SEO (2016) conclude that SDE+ has stimulated entrepreneurs to choose RES at the lowest possible cost, and achieved cost savings of around 11% over the period 2011-2015 compared to the previous (technology-specific) programmes. The study also shows that the subsidy granted for energy produced (€/MWh) - has decreased from 43 to 27 €/MWh from 2011 and 2012, and then stayed relatively stable in the period 2012-2015, ranging from 27 to 33 €/MWh. It also finds that the proportion of free riders has been rather limited, i.e. 5-15%. However, AURES (2019) points out that the decrease in support levels for most of the technologies from 2017 onwards has been mainly driven by decreasing ceiling prices. AURES (2019) stresses that the cost of the support typically depends

[94] To be eligible, applicant need to submit a profitability calculation to show the project could be implement only thanks to the support. The climate benefit ratio can be lowered for projects that are considered particularly relevant (e.g. charging stations for electric cars) or that contribute to other general state objectives (e.g. dissemination of a certain technology). In those cases, it is only required to reach 80% of the quota. In the case of an equal reduction of carbon emission per SEK, aspects such as effects on other environmental quality goals, employment effects and distribution, as well as introductions to new technology are taken into account.
[95] For instance, *Klimatklivet* includes both applications that lack alternatives and those that involve changing technology: in the first case, it is required to look at the entire investment cost, but in the latter case, the additional cost of the more climate-smart investment is more relevant. The quantification of the CO2 emissions reductions may be overestimated in some cases, due to double counting and the inclusion of unrealized emission reductions (see also Box 3).
[96] Applicants to SDE++ have the possibility to submit their project in the free category, according to which projects with higher costs can apply for a subsidy level lower than the maximum base rate (i.e. estimated average production costs of renewable energy, heat and gas, determined annually) of the category they apply to.
[97] This is based on a survey to the stakeholders, undertaken by CE and SEO (2016) and the Netherlands Enterprise Agency (RVO).

upon one price-setting technology, which influences the prices of all the others because either i) more expensive technologies reduce their price level or ii) cheaper technologies bid up to their price ceiling.[98] Moreover, both CE and SEO (2016) and Catapult (2018), stressed that the high level of competition of SDE+, coupled with the risk of budget exhaustion, leads to underbidding. This is in line with the findings of AURES (2019) which show that up until 2014 almost 50% of the auctioned volume was not realised.[99] To reduce the risk of non-committal subsidy application, CE and SEO (2016) suggest an entry fee to be refunded in the event of budget exhaustion or project realisation.[100]

The Dutch and Swedish experiences with multi-sector schemes, SDE+ and *Klimatklivet* respectively, produced very different results. The differences in the programmes' design could have potentially played a role: SDE+ is a pay-as-bid auction, whereby participants receive a sliding FIP that compensates the difference between the bid (€/kWh) and the market price of RE. Bids are capped by technology-specific ceiling prices, which may prevent windfall profits for the least costly technologies, and phase ceiling prices which help driving down the costs of the most expensive technologies. In addition, to ensure high realisation rates and avoid underbidding, the scheme requires strict pre-qualification criteria and foresees penalties for non-realisation of projects starting from 2014.On the other hand, *Klimatklivet* is a direct grant, which is awarded to applicants that deliver projects with the highest climate benefit ratio: this measure requires to properly calculate the amount of emission reductions these projects are expected to generate (SEK/tCO_2e), a step identified as crucial by both WSP (2017) and Riskrevisionen (2019). The scheme requires a simple initial screening: applicants need to submit a profitability calculation to demonstrate their project to be feasible only through the aid. Once they meet this basic criterion, applications are ranked based on their climate benefit ratio.[101] Other than the programmes design, SDE+ and *Klimatklivet* target significantly diverse technologies, which makes them hard to compare: while SDE+ was only opened to RES-E and RES-H[102], the group of technologies promoted by the Swedish programme is very large and diverse (e.g. energy conversion measures, biogas production as well as electric vehicles charging stations).

The overall positive results of SDE+ led to broaden the eligible technologies and sectors in the subsequent scheme SDE++, which focuses on GHG reduction rather than energy production from RES. There are five main eligible categories of technologies for SDE++: RES-E, RES-H, renewable gas, and low-carbon heat (e.g. waste heat) and production (e.g. CCS).[103] Similarly to SDE+, eligible technologies compete under one budget ceiling[104] and beneficiaries receive a sliding FIP determined on the basis of multi-technology and multi-phase auctions. In addition, technology-specific price ceilings and phase price ceilings are defined. Differently from SDE+, eligible projects compete on the basis of (expected) subsidy requirements per avoided tonne of CO_2 equivalent instead of competition on the basis

[98] For instance, the study points out that in 2012 the low support level for solar PV was due by an early budget exhaustion, caused by the large amount of relatively cheap biomass projects that used up the budget and thus acted as price-setting technology. For that reason, only solar PV projects sufficiently cheap that could afford to bid in the first phase were awarded at a very low technology specific ceiling price.
[99] AURES (2019) adds that the introduction of feasibility studies and stricter permitting rules helped addressing the low realisation rates: as of 2019, only around 10% of project capacity in 2015 was not realised.
[100] It is worth noticing that the scheme already envisages prequalification requirements which include *inter alia* feasibility studies and environmental permits. In addition, SDE+ impose penalties for beneficiaries that fail to realise projects within a required period.
[101] Only in the case of an equal reduction of CO_2 emission per SEK, aspects such as effects on other environmental quality goals, employment effects and distribution, as well as introductions to new technology are taken into account.
[102] Please note, however, that the subsequent scheme SDE++ has been opened to electrification technologies and CCS too, including hydrogen production.
[103] See https://english.rvo.nl/subsidies-programmes/sde.
[104] The one budget ceiling rule can have three exceptions and technology specific ceiling can be set in the following cases: 1) an (indicative) ceiling of 7.2 megaton (i.e. million tonnes) for CCS in industry in 2030 and a ceiling of 3 megaton for CCS for electricity, considering a limited time horizon; 2) an (indicative) ceiling of 35 TWh on the eligible production of renewable electricity from solar and wind energy; 3) an (indicative) ceiling of €550 million (cash expenditure in 2030) for CO_2-reducing options in industry, other than for the generation of renewable energy (see https://www.dentons.com/en/insights/alerts/2020/april/16/ams-dutch-subsidies-for-renewable-energy-the-end-of-the-sde-scheme).

of the cost price for renewable energy.[105] PWC (2020) argues that, thanks to the programme's shifted focus and in particular the inclusion of emissions reducing technologies such as CCS, Netherlands is a frontrunner internationally in subsiding large-scale emission reduction in the industry. However, it is too early to have comprehensive evaluation results. PWC (2020) identifies two potential shortcomings. First, some companies are unable to receive support even if there are cost-effective emission reduction options available for which part of the investment is unviable.[106] This may have an impact on the level playing field and alter the Dutch industry competitiveness. Second, the subsidy does not seem to cover some relevant costs for electrification technologies, such as the reinforcement of the network connection, or other costs related to access to infrastructure (e.g. heavier electricity grid connection costs or the costs of transport form CO_2 capture locations further form the storage location). This, together with legislation and regulatory barriers, may hinder investments in large integrated projects, which would help creating a sustainable ecosystem.

Finally, other multi-sector schemes include broad energy efficiency programmes aiming at reducing both CO_2 emissions and energy consumption, which mainly envisage energy-saving technologies (e.g. CHP) and sustainable energy production (industrial decarbonisation technologies, energy efficiency programmes). These schemes may also include renewable production and are generally based on tax deductions or direct grants. Both the German energy efficiency programmes (i.e. the Energy Efficiency Fund, the STEP up![107] and the MAP) and the Dutch EIA proved to be successful and cost-effective, although the EIA has also attracted free-riders. It is hard to understand to what extent the open-ended structure of the scheme contributed to the free riding.

The EIA, introduced in Netherlands in 1997, is a multi-sector and multi-technology programme that reduces beneficiaries' upfront investment costs related to energy saving and sustainable energy technologies through an income tax deduction. Eligible technologies are presented once a year on the so-called Energy List. To be included in the List, they must meet a substantial reduction in energy consumption, and they should not (yet) be in common use. By including new and hardly adopted technologies, the List acts as an information device and reduces search costs. Vollebergh and Ruijs (2013) consider this as one of the key factors for the success and survival of the scheme. They also measure cost-effectiveness in terms of € of tax expenditure per tonne of CO_2 equivalent avoided, and show that it decreased over time, moving from 4-7 €/tCO_2e avoided in 2010 to an average of 14 €/tCO_2e avoided between 2012 and 2017. However, when considering free riders[108], the cost-effectiveness varies between 21-46 €/tCO_2e avoided. Vollebergh and Ruijs (2013) argue that free riding is a major issue raised by the programme. This may be partly explained by the difficulties in making completely separate incentive contracts: due to differences in technology-specific payback periods per sector, technology that seems to meet the standards for one sector may be considered a free rider technology for another. The scheme has been refined over time, envisaging maximum energy saving standards, subsequently made more stringent and category dependent, and by focusing on energy saving (and no longer also sustainable) technologies starting from 2013. Despite such efforts, the share of free riders is still around 50% of the EIA applicants (Vollebergh and Ruijs (2020)). Vollebergh and Ruijs (2013) also discuss the concerns related to the EIA overlapping with other national schemes[109], and the counterproductive interaction of EIA with EU ETS, especially for RES and CHP.[110]

[105] When generating renewable electricity, the CO_2 reduction is calculated on the basis of replacing the average CO_2 emissions of an efficient modern gas-fired power station. See https://www.dentons.com/en/insights/alerts/2020/april/16/ams-dutch-subsidies-for-renewable-energy-the-end-of-the-sde-scheme .
[106] Certain technologies do not yet qualify for SDE++ (e.g. CCS by ship) or qualify just a limited extent (e.g. circularity projects such as Waste 2 chemical technologies).
[107] SA.45538 STEP up!.
[108] Defined as companies who would have invested in cleaner technologies even without the aid.
[109] MIA (Environmental Investment Allowance), VAMIL (Random Depreciation of Environmental Investments) and MEP (Environmental Quality of Electricity Production).
[110] Such investments reduce demand, and in turn, prices of permits, which – given the overall cap – enables emissions by other installations or firms to be covered by ETS. This also applies to energy saving technologies:

Free riding does not seem to be a problem for the broad German energy efficiency programmes, which proved to be quite successful. Frauenhofer ISI et al. (2019) evaluated the German Energy Efficiency Fund over the period 2011-2017, a programme that included several regulatory, economic or information measures targeted at industries, private consumers, and municipalities. The study assesses the performance of the scheme based on (i) a measure of cost-effectiveness for the whole programme, computed as the ratio of the support[111] to the CO_2 emission reduction achieved, which ranges from 2.2 to 90.9 €/tCO_2; (ii) the leverage effect, i.e. how much investment is triggered with one euro of aid, which ranges from 3 to 96 €; (iii) a measure of the cost of energy savings achieved, resulting in 0.7 to 29.7 €/MWh.[112] The study finds that both the Energy Efficiency Fund as a whole and its individual measures make a positive contribution to the reduction of GHG emissions and energy consumption and thus lead to substantial energy cost savings.

DBI-GUT et al. (2019) examined the German MAP, a scheme aimed at financing low-carbon heating technologies through investment subsidies and low-interest loans. They find that, on average, the programme results in a cost-effectiveness of approximately 37 €/tCO_2e, while the leverage effect ranges from €4 to €5.1 invested for each €1 of support. In addition, the study analyses the programme's positive impact on competition, measured by the reduction of heat production costs[113] and market concentration: the biomass and the heat pumps markets, for which HHI is calculated and compared in 2017 and 2018, are not concentrated, and heat production costs show a decreasing between 2016 and 2018.

Finally Ifeu and Prognos (2019) provide the results of a survey assessing the German pilot programme STEP up!, a broad programme encompassing both electricity efficiency measures and CHP technologies that, differently than the schemes previously assessed, is based on a competitive tendering procedure. The results of the survey show that one of the main advantages of STEP up! is the reduction of financial barriers, namely the reduction of the payback period. The paper argues, however, that compared to other programmes, the pilot of STEP up! proved not to be very cost efficient and this depended on the high fixed- and start-up costs. This is reflected in the cost-effectiveness estimate which is slightly below the estimate of the similar measures within the two German broad efficiency programmes previously assessed: on average, 28 € have to be spent to save one MWh of electricity, while, in order to avoid one tonne of CO_2 equivalent, 54.3 €[114] of aid are necessary. The leverage effect is around 6 euros of investments for each euro of support. Langreder et al. (2019) stress that the tendering approach takes time to get used to and requires more effort from applicants[115]; however, strengthening the programme marketing and application support, especially close to the target audience, proved to be helpful. The paper also argues that the openness to actors and technologies has been perceived as the major strength of the STEP up! and, during the pilot phase, stakeholders prompted

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firms can sell more permits and lower their prices. This would result in a reduction in electricity prices, thus increasing energy demand and potentially cancel out the initial energy savings.

[111] Specifically, it is defined as the total expenditure in terms of support provided plus all expenses for implementing the measures.

[112] All the indicators are calculated in terms of kgC02 equivalent/€ and kWh/€ as well.

[113] The study compares heat production costs for pellet boilers, logs, brine to water pumps, air to water heat pumps, solar flat plate collectors and solar vacuum tube collectors in the period 2016-2018 and assumes constant economic conditions (i.e. constant energy prices). Production costs are adjusted for inflation.

[114] Ifeu and Prognos (2019) provide a list of energy efficiency measures envisaged by the Energy Efficiency Fund that could be compared to STEP up!. These are: 1) Abwärmerichtlinie, 2) Energiemanagementsysteme, 3) Produktionsprozesse, 4) Einsparcontracting, 5) Energie- und Stromsparchecks, 6) Querschnittstechnologien. When considering these measures, the cost effectiveness estimates range from 4.1 to 57.6 €/tCO2e, the leverage effect from 3 to 14.3 €, and cost energy savings from 1.5 to 40.6 €/MWh. Only the "Querschnitttechnologien" programme measures achieved similar values to STEP up!. However, according to Ifeu and Prognos (2019), Querschnittstechnologien had a relatively bad performance compared to other schemes because of the considerable number of free riders.

[115] The survey conducted during the pilot phase showed that stakeholders perceived higher risks to fail and effort compared to classic efficiency funding programs, and the funding rate was comparable. In particular, respondents identified several critical points, *inter alia* i) the application process and the preparation of required material was perceived as time consuming; ii) identification and description of the energy efficiency measure as well as the calculation of the electricity savings; iii) support potentially not sufficient to offset the cost of participating in the tender and of proofing the electricity savings.

for the inclusion of heat technologies. Overall, although the programme did not reach the expectations, the competitive tender funding has proven its worth.

Annex 1.4 provides two graphs comparing the available estimates of cost-effectiveness for the reviewed schemes for the five categories identified above.

This section reports the results of multi-technology and technology-neutral schemes for RES-E support and multi-sector schemes for decarbonisation, implemented by the Member States in the last decade. Evidence shows that multi-technology schemes are more cost-effective, they lead to oversubscription and reduce the cost of support, but crowd-out more expensive technologies (e.g. hydro and biomass) and small players. The comparison of two multi-sector schemes, namely SDE+ in the Netherlands and *Klimatklivet* in Sweden, demonstrate that the design of a subsidy scheme plays potentially a crucial role in a programme's cost-effectiveness and can lead to significantly different results. Evidence from Germany shows how broader energy efficiency programmes have been generally considered successful: in particular, STEP up! proves tendering could be extended to other areas then the ones currently envisaged by the EEAG. Finally, the above literature shows that Member States are increasingly relying on the cost-effectiveness assessment for decarbonisation schemes, thereby moving away from approaches based on EUR per unit of energy produced, which ignores the contribution of the measures being aided to the environmental protection objectives.

1.3 Case studies: methodology

This section presents case studies on the cost-effectiveness of support schemes in the field of energy and industrial decarbonisation in Denmark, Germany, and Poland and a simulation of potential impacts of broader tenders. An overview of the different schemes considered is given in Table 1. The cost-effectiveness is assessed for the support granted through the schemes between 2015 and 2019, whereas the impacts of broader tenders are simulated for a specific year in the static simulation.

Table 1: Overview of support schemes considered in the case studies

Country	Scheme	Technologies supported	Cost-effectiveness	Static simulation
Denmark	SA.40305, SA.43751, SA.45974	Offshore wind	Individual auctions 2015/16	Individual auctions 2015/16
	SA.49918	Onshore wind & solar	Multi-technology (MT) auctions	Multi-technology (MT) auctions
	SA.35486, N602/2004	Industrial CHPs	Support from 2015	Support from 2015
Germany	SA.45461	RES	Onshore wind & solar auctions, solar admin. support	Onshore wind & solar auctions
	SA.42393	CHP	Auctions & admin. support	Auctions
	SA.45538	EE	Auctions	Auctions
Poland	SA.43697	RES	MT auctions onshore wind & solar	MT auctions onshore wind & solar
	SA.51192	CHP	Auctions & admin. support	Auctions
	SA.43254	EE	Admin. support	-

Source: DIW Berlin.

The dynamic simulation is developed for the case of Germany for onshore wind, offshore wind and PV. In contrast to the cost-effectiveness and the static simulation, the dynamic simulation is investigating future tenders.

This section presents the methodology that was used for the assessment of cost-effectiveness and the simulation. Further details on the methodology and data used can be found in Annex 1.

1.3.1 Cost-effectiveness of selected schemes

Cost-effectiveness is usually defined as the costs attributed to the attainment of (environmental) benefits.[116] In this case study, we focus on the decarbonisation achieved by the support mechanisms as the main benefit. Thus, we determine the cost-effectiveness by the associated effective support divided by the net mitigated CO_2 emissions. Other non-CO_2 environmental benefits not quantified are indicated separately later in this section. The effective support considers the public aid granted through the considered schemes and the implicit support of carbon pricing under the EU Emission Trading System (EU ETS)[117], both over the support duration as defined in the respective schemes and discounted at a social discount rate of 2%[118]. Net mitigated emissions include avoided emissions from displacement of fossil electricity and heat generation and fuel savings, as well as generated emissions. These are calculated either over the entire lifetime of installed technologies for renewable energy sources (RES) and energy efficiency measures (assuming 20 and 10 years, respectively) or over the duration of support for combined heat and power (CHP) plants, since for the latter it is uncertain whether the installations will remain in operation without operating aid.[119]

$$Cost\ Effectiveness = \sum_t \frac{EffectiveSupport_t\ [EUR] * \frac{1}{(1+\delta)^t}}{Net\ Mitigated\ CO2\ Emissions_t[tonCO2]}$$

Since our measure of cost-effectiveness focuses on the mitigation of CO_2 emissions and includes both explicit support through the aid schemes as well as implicit support through the EU ETS, it is effectively a measure of carbon mitigation costs.

Each of the categories as well as benefits or costs that could not be monetarised in the scope of this study will be discussed in more detail below.

1.3.1.1 Mitigated CO_2 emissions

The determination of mitigated CO_2 emissions requires a counterfactual to be defined. We assume here that the counterfactual is the absence of the investigated part of the selected support schemes, including direct operational (e.g., changes in the merit order) and investment impacts (e.g., marginally more investment in other technologies) in the electricity sector, as well as other coupled sectors. Both effects will be discussed in more detail later.

We assume the overall impact of the analysed support schemes on the overall energy system and markets to be marginal and that the system is on an equilibrium pathway represented by the chosen reference scenario120. This allows us to simplify the analysis to the marginal impact of the respective policy in question.121 Additionally, we disregard

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[116] If several benefits (or other non-monetary costs) are accrued, either (i) the cost needs to be attributed to several benefits, and thus split, (ii) other benefits need to be monetarized and subtracted from the cost, or (iii) not included in the cost effectiveness index, and separately discussed.

[117] In the scope of this study, we do not consider additional policy mechanisms in the respective Member States, such as carbon taxes on fossil fuels in the heat sector, that may provide additional effective support to the technologies included. If such policies are in place, these would increase carbon mitigation costs compared to the results reported in this study.

[118] A recent study by Drupp et al. (2018) found that a large majority of experts considers a social discount rate of 2% acceptable. The sensitivity analysis (see Annex 3.2) considers an alternative discount rate of 5%.

[119] The considered RES technologies are typically not associated with significant (incremental) variable costs, which is why they can be assumed to continue operating even without support in the form of operational aid (relevant for Poland and offshore wind in Denmark, where the duration of support is shorter than the assumed lifetime of 20 years). For CHPs, on the other hand, it is uncertain whether the revenues generated on the market will be sufficient to cover variable fuel and CO2 costs without operating aid. We therefore assume in the reference scenario that CHPs only operate until the end of support and present sensitivities (see Annex 3.2) for the alternative assumptions that the CHPs continue operating until the end of their respective lifetime 1) without continued support and 2) with the same level of support (in the case that the support will be extended).

[120] The cost effectiveness is discussed against the background of high reduction targets (for example 95% CO_2 reduction over all sectors), and associated high levels of variable renewables. Where not discussed explicitly, the framework also applies to lower targets.

[121] However, it should be noted that some support schemes under investigation are large enough to have non-marginal impacts.

the marginal effect on price changes of the EU ETS, which overlaps with the sectors under investigation (Section 1.2.1). Instead, we add an ETS price component to the costs, that indicates the support level that would be needed in the absence of emissions prices. A similar approach has been used in previous studies (Section 1.2.1).

Below we will conceptually discuss carbon mitigation effects of three different technologies, with a focus on the structure of the current and future power sector.

In case of renewable technologies three cases of carbon displacement (or its absence) in the power sector need to be distinguished.

- **Direct replacement:** The first channel is via direct displacement of production and emissions from fossil fuel sources, in hours in which these are marginal (according to the hourly profile of the renewable technology). This is the case up to high shares (around 50%, Annex 2.1) of renewable or nuclear energy, as these, due to their lower variable costs, precede the conventional sources in the merit order;
- **Replacement in adjacent hours:** Additional renewable power generation in hours in which renewable power is already marginal will trigger additional storage or flexible use of *sector coupling technologies*[122] (e.g., EVs, electrolysers, and processes that can switch between electricity and other energy carriers). Storage is then discharged, or flexible demand replaced in the expensive hours of the year where conventional technologies are still producing, leading to mitigation of the emissions associated with this production;
- **Curtailment of renewable technologies:** As it is not cost-optimal to completely avoid the system-wide, as well as grid-related curtailment of renewable energy (i.e., install sufficient storage or flexibility options to use the yearly renewable production peak), both short- and long-term analysis show that a certain level of curtailment occurs.[123] Additional production of electricity in already curtailed time periods will not replace any generation, and hence only in this case, no mitigation of carbon emissions is achieved.

While in a short-term perspective, storage capacities are constrained, in the longer-term perspective, additional renewable generation will result in an extended period and spread between hours with low- and with higher prices. This in turn triggers – in equilibrium – additional storage and flexibility investment.[124]

In equilibrium we will observe, that with increasing renewable penetration, the market value of renewables is gradually declining. This reflects the increased number of hours of low-prices and spread towards high prices – necessary to remunerate the increasing capacity of storage or flexibility provided to the system. However, this does not necessarily imply that the carbon mitigation per extra unit of renewable generation is declining in parallel. On the contrary, as long as sufficient storage and flexibility potential exists or is added in equilibrium, and if electricity generation remains based on the same fossil fuels mix in the investigated period, the carbon mitigation per MWh of additional renewable electricity remains at the same level.

In contrast the effect of additional renewables on (their) potential revenues (market values) are stronger than on curtailment, and also need to be considered when evaluating the support levels. Annex 2.1 discusses the effects of increasing shares of renewables on curtailment and the power system equilibrium in more detail.

For CHP technologies the carbon mitigation effects of generated electricity follow the discussion for generation from RES, i.e. an additional CHP-generated MWh of electricity either replaces fossil generation in the same or adjacent hours, or leads to no mitigation

[122] See Annex 2.1

[123] The level of curtailment tends to be smaller with more ambitious carbon mitigation scenarios, as the energy is used in sector coupling (Victoria et al., 2019; Bernath et al., 2021). Optimal curtailment levels may also be different between technologies.

[124] Studies on systems with high shares of renewable (Brown et al., 2019) show that an increasing share of renewables (and lower emissions levels) are accompanied by investments in storage and sector coupling technologies.

in hours of curtailment.[125] In addition, carbon mitigation effects in the heat sector, where usually fossil heat generation is displaced, and generated emissions in case of fossil fuel-fired CHPs need to be considered.

For energy efficiency measures affecting electricity consumption and under the assumption that energy efficiency measures are needed to achieve the policy targets[126], energy efficiency displaces conventional marginal generation, except for times of renewable curtailment. If energy efficiency measures lead to heat savings, the associated carbon mitigation in the heat sector needs to be considered as well (analogue to the approach for CHP). In the case of direct fuel savings, mitigated emissions can be easily calculated using the carbon content of the respective fuel.[127]

To capture the main effects outlined above in a tractable way, we use a simplified analytical framework that allows a sensitivity analysis of the main determining factors. These factors include key parameters such as curtailment factors (and market values in the cost index), which can vary strongly depending on scenario assumptions in larger models (e.g. Winkler et al., 2019).

As a basis for the determination of carbon mitigation we propose to extend the methodology of establishing emission factors applied for the determination of the maximum state aid for indirect cost compensation[128], to the effects of renewable curtailment (a similar approach has been used for instance by Öko-Institut, 2015).

The mitigated CO_2 emissions per MWh of electricity generated are determined based on the average emissions of the remaining fossil generation in the system in each year *t* and country (or price region) *Geo*.[129] This emission factor is corrected for the curtailment that is taking place during the generation profile of the respective technologies. This is done using curtailment factors, which, for RES technologies, correspond to the share of renewable electricity generation that is curtailed, and, for CHP and energy efficiency measures, to the share of curtailment in total electricity generation in the respective year and country (price region).[130]

$$Mitigated\ CO2\ Emissions_{t,Tech,Electricity} = \frac{EmissionsFromFossilGeneration_{Geo,t}\ [tonCO2]}{ElectricityGenerationFromFossils_{Geo,t}\ [MWh]} * \left(1 - CurtailmentFactor_{t,Geo,Tech}\right)$$

In the case of wind and solar generation, no additional CO_2 emissions or savings are taking place and hence net mitigated emissions equal mitigated emissions in the electricity sector. For CHPs, additional emission savings from displacement of fossil heat generation as well as generated emissions are considered.

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[125] If CHPs are operated flexibly, they would typically not generate electricity in hours with curtailment and low electricity prices, hence all generated electricity can be assumed to replace fossil generation. For the purpose of this study however, we assume that all CHPs are operated inflexibly, thus also in hours with curtailment.

[126] Confer Annex 2.2 for an alternative assumption.

[127] In the case studies, we are currently only considering carbon mitigation in the electricity sector, since there is no data available on the heat and fuel savings under the considered schemes and, in the German case, the scheme was primarily focused on electricity savings.

[128] Communication 2020/C 317/04 Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021.

[129] Following the newly defined regions in Communication 2020/C 317/04, we use the emission factors of fossil electricity generation for the price regions Germany-Austria-Luxembourg, Denmark and Poland for the respective case studies. Assuming these relatively narrow price regions generally underestimates the effect of price convergence over the broader regions. An alternative would be to take an average of national and larger price region emission factors; however, future projections of price convergence are not commonly included in scenarios.

[130] Due to different generation profiles of RES technologies, the actual curtailment factors may differ between technologies. Since reported curtailment rates are usually only reported for total RES generation, or, where this is not the case, are highly sensitive to model settings (e.g. which technology is curtailed first in case of excess supply), we assumed for this study that curtailment rates are equal between RES technologies. CHPs and energy efficiency measures are assumed to operate inflexibly as baseload technologies, hence the share of generation that takes place during hours with curtailment is lower than for RES technologies (corresponding to the share in total electricity generation). Grid-related curtailment is not considered in the reference scenario, but instead shown to not have large impacts on our results in the sensitivity analysis (Annex 3.2)

The calculation of mitigated emissions from generated heat displacing (other) fossil heat generation is similar to the case of electricity. Specifically, we assume that per MWh of generated heat, the average emission intensity (tCO_2/MWhth) of the remaining fossil heat generation mix in the system in the respective year and country are avoided.[131] Net mitigated emissions are then equal to the sum of mitigated emissions in the electricity and heat sector minus generated emissions from CHP production. The latter are calculated by dividing the electricity and heat generation (output) by the overall (thermal + electric) efficiency of the respective CHP plant to obtain the primary energy (fuel) input, and subsequently multiplying the result with the emission factor of the respective fuel type (tCO_2/MWh). For a more detailed description of the methodology, see Annex 2.2.

1.3.1.2 Effective support

As effective support, we consider the public aid granted from within the schemes as payments above market values and an ETS price component to account for the implicit support provided by the carbon pricing of electricity generation. Compared to the approaches in the literature review (Section 1.2.1), fuel cost savings, carbon costs savings and capacity savings are implicitly included in the market values of the technologies.

$$EffectiveSupport_t = PaymentsAboveMarketValues_t + ETSPriceComponent_t$$

While in the case of fixed premia, payments above market values are constant, for sliding premia and CfDs the payments depend on market prices. In this case, payments are estimated using historical and projected market values for the investigated technologies. Since market values reflect the different system integration costs of intermittent RES technologies (e.g. profile costs, compare e.g. Ueckerdt et al., 2013), these are implicitly included in our analysis. Investment aid is considered as a one-time payment in the year in which the aid was granted.

The ETS price component captures the effective support given by the carbon pricing of the electricity sector, which leads to higher electricity prices and hence increases the revenue for supported installations (or savings for energy efficiency measures). In addition, the inclusion of this component makes the indicator robust to changes to the ETS market prices over time or scenarios for sliding premia and CfDs, since higher ETS prices lead to an increased ETS price component, but also translate to higher electricity prices and thus reduced public support. This is in line with the findings of the literature review (see section 1.2.1).

To determine the ETS price component, we estimate the impact of carbon prices on electricity prices using an adjusted approach for the calculation of the carbon mitigation. To do this, the CO_2 price in year t is multiplied with the average emission factor of fossil electricity generation of the respective country and year t, corrected for the share of hours in which non-emitting technologies are on the margin (*ShareMarginalNonEmitting*, SMNE). This approximates the average absolute carbon costs (in €/MWh electricity) that are passed through to the electricity price. When the share of hours in which renewable generation is curtailed and non-emitting technologies are on the margin is zero or very low, this approach is comparable to simply adding the CO_2 price to the effective support.[132]

$$ETSPriceComponent_t = CO2Price_t * \frac{EmissionsFromFossilGeneration_{Geo,t}}{ElectricityGenerationFromFossil_{Geo,t}} * (1 - ShareMarginalNonEmitting_t)$$

The SMNE reflects the share of hours of a year in which the carbon content of fossil generation is not influencing the price. In contrast to the carbon mitigation case, these are not only the hours in which renewables are curtailed (i.e. on the margin), but also those

[131] This assumes that CHP-generated heat does not displace heat generation from renewable sources. The possibility that this is not the case and e.g. heat generation from biomass is displaced is considered in the sensitivity analysis, where we calculate with the alternative assumption that the average emission intensity of the entire heat generation mix (including e.g. biomass) is displaced (compare Annex 3.2).

[132] In the case studies below, this is the case for Germany until about 2030 and Poland over the entire time horizon of this study (compare underlying scenarios in Annex 2.3). Note that the emission factor of fossil generation cancels out for technologies other than CHP as it also appears in the calculation of mitigated emissions from electricity generation.

hours where a charging storage or flexible demand (both of which do not have a CO_2 impact) are price setting.[133] However, since an approximation of this share has been difficult due to a lack of literature and sufficiently detailed data, we adopted the assumption that the SMNE equals the curtailment rate of the respective year and country. While this approximation is likely to be close to the reality in the short term, it underestimates the SMNE (and hence overestimates the ETS price component) in the long term, when charging storage and flexible demand are expected to become increasingly marginal (Härtel & Korpås, 2020).

In terms of co-benefits and costs, the inclusion of technology-specific market values already implicitly includes parts of the system integration costs of the considered technologies. In addition, we consider grid-related curtailment in the sensitivity analysis for Germany (see Annex 3.2).

1.3.1.3 Data

For our calculations, we rely on historical data up to 2018 or 2019 on the electricity and heat generation mix, associated emissions, as well as electricity and CO_2 prices. Projections of these parameters up to 2050 are based on the PRIMES Reference 2020 scenario, which models the development of the energy sectors of the respective countries under the established policies (not considering the increase of ambition for the 2030 targets). System-related RES curtailment rates and market values are projected based on a literature review of mid- to long-term energy models and matched to the market shares of RES technologies in the respective country and year as projected in the underlying PRIMES scenario. Support levels and volume under the considered schemes are derived from various public and non-public sources (for a detailed description of the data and assumptions used, see Annex 2.3).

1.3.1.4 Limitations of the approach

Due to the limited scope of this study, several co-benefits and costs are not considered in the assessment of cost-effectiveness of supported technologies. While the investigated schemes usually focus on decarbonisation, potential other environmental externalities include impacts on biodiversity, resource efficiency, quality of air and water, and land use. In addition, health benefits from reduced air pollution, which was an explicit goal in the Polish CHP scheme, are not considered. On the cost side, redispatch and congestion costs are not quantified, as an attribution of costs between inflexible generators and renewable would be necessary and since there is no data-basis on future inner-country congestion costs.

Other effects that are not considered and typically difficult to quantify are impacts on energy security, social acceptance, resilience of supply chains, employment and innovation.

The cost-effectiveness methodology cannot capture the dynamic impact larger programmes have on overall system costs and the EU ETS. Among the dynamic effects are potential path dependencies created by support mechanisms, including endogenous effect learning can have on the levels on future installations.

Furthermore, the methodology assumes that marginal generators are, except in the hours of renewable curtailment, fossil generators. This may not hold if CCS generators or other flexible low-carbon generation start to play a major role and are dispatched as a flexible price-setting technology. In addition, the potential displacement of nuclear energy (leading to no carbon mitigation, but other environmental benefits) needs to be considered when applying the methodology to countries characterised by high shares of nuclear energy generation so that nuclear energy is the marginal technology. However, this is not the case for any of the investigated case studies and few European countries have high enough shares of nuclear generation for this to be the case[134]. It needs to be noted though, that

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[133] In hours where storage is discharging, the carbon price is implicitly included, as it just underbid marginal emission-intensive generators.

[134] Even in France with around 70% of overall installed capacities being nuclear, from 2016 to 2018, nuclear power plants were only marginal for 10-20% of hours, and in 2019, 36.8%.

due to the limited flexibility of nuclear energy it may be curtailed instead of renewables and thus be captured in the curtailment parameter.

1.3.2 Static simulation of multi-technology tenders

To analyse the effect of changing the technology-specific auctions to a broader multi-technology framework, we develop a simulation model that allows us to compare the two auction frameworks.[135]

We analyse the effect of the policy change in the three countries (Denmark, Germany and Poland) analysed in the cost-effectiveness study (see previous section). For each country, we consider technologies that are currently part of technology-specific or multi-technology auctions. For all countries these are onshore wind, PV and CHP. For Germany, we additionally include energy efficiency and for Denmark we further consider offshore wind. Due to data availability reasons, we include a differing set of years for each country. These are 2017-2019 for Germany, 2018-2019[136] for Denmark and 2019 for Poland. To make the scenarios comparable, we assume that the support mechanism and the duration of support that were in place during the technology-specific auctions continue in the multi-technology setting.

For our analysis we combine data from the cost-effectiveness study with further data sources. To begin with, we used the information on auction results from the cost-effectiveness study. To conduct our simulation study, we also collected additional information on technology costs from Kost et al. (2018) (Germany), the Danish Energy Agency (2021) (Denmark) and our own calculations based on the literature (Poland). A detailed list of the data sources used can be found in the annex.

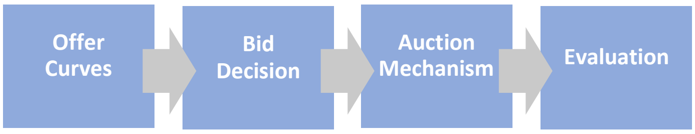
A limitation of our analysis is that our simulation is based on a simplified representation of auction participants’ costs and offer curves. However, due to data limitations this is a necessary assumption. Furthermore, we do not consider market power or strategic behaviour by auction participants. Additionally, the static simulation shows an incomplete picture, as it omits the long-term effects of altering the technology mix of supported projects (e.g., capacity constraints, learning benefits etc.). To address this, we developed a dynamic extension that is presented in the following section.

In this analysis, auctions are simulated as uniform pricing auctions, while in practice the auctions are usually implemented as pay-as-bid. In first order this a good approximation, as under pay-as-bid bidders can anticipate the auction result and rather than bidding their true cost, try to bid as closely to the expected auction result, while still expecting to be accepted (reference to auction theory literature is detailed below) so that the outcomes under pay-as-bid and uniform price auctions will be comparable. The implementation of the auctions as a uniform price auction omits some strategic incentives that come into play in the presence of price caps and undersubscribed auctions, and under high levels of uncertainty bidders would make offers closer to their true costs, which mitigates inframarginal rents. However, as argued below, economic theory and observations of auctions supports our argument that the results of our analysis should not be strongly affected by these considerations.

[135] For the entire analysis we assume a discount factor of 2% and an inflation rate of 1% in accordance with the previous section. All prices are expressed in 2015 Euros except for Poland where support payments are calculated in current prices.

[136] As we only have data for the 2015-2016 offshore auctions in Denmark, we combine these with the data for other technologies that runs from 2018 to 2019.

Figure 1: Set-up of the model



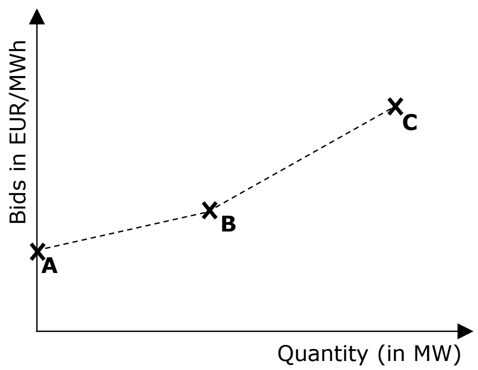
Source: DIW Berlin.

The model consists of five main steps that are described in Figure 1 and below:

Construction of offer curves: The input data is imported from the cost-effectiveness study and the data sources described above. The data consists of auction-specific data describing the run hours, prices and quantities of the technologies competing in that auction at three points:

- **Point A:** From the literature we take the minimum LCOE feasible for the corresponding technology in each country. The corresponding quantity (Q_A) is zero.
- **Point B:** From the auction results we take the last price that was awarded support in the auction. Q_B is determined by the volume supported in the auction.
- **Point C:** From the literature we also get point C, indicating the highest feasible price for the technology. We match this value to Q_c, the maximum yearly quantity derived from 2030 capacities in the Primes reference scenario.[137] In cases where $Q_B > Q_C$, we set them equal, i.e. assume that there is no excess capacity.

Figure 2: Example of an offer curve



Source: DIW Berlin.

We then use the input data to construct offer curves for each technology and auction by interpolating between the points A, B and C. In this, we treat each MW of capacity as a separate bid in order to limit discontinuity issues associated with using discrete input data. In years with multiple auctions, we afterwards combine the offer curves to a yearly supply curve. Figure 2 shows a possible offer curve. The underlying assumption of our approach is that auction participants reveal their true costs when making their bid (i.e., that the auction mechanism is incentive compatible).

Further input data is taken from the cost-effectiveness study discussed in the previous section. We use technology-specific information about market values, emission intensity, run hours and curtailment to determine the support in each year of the supported operation of the plant or energy efficiency measure. We combine the time-series and the information on offer curves to construct the available potential of installations that are competing in each auction. For a schematic overview of the data used in the study see the figures in Annex 2.4.

[137] In years with more than one auction, Point C is determined as $\frac{1}{n} *$ PRIMES capacity.

Auction Mechanism: A variety of clearing mechanisms are applied in electricity market auctions (e.g. pay-as-bid, pay-as-cleared). If a set of assumptions such as perfect competition, complete information and no uncertainty are met, then all mechanisms result in the same auction outcome ("Revenue equivalence theorem"). We assume that – in first order – these assumptions are met and that the auction will allocate the support to the most efficient installations participating. Further, we assume that all bidders will receive the marginal clearing price. This is a reasonable assumption, as in pay-as-bid auctions the 'lower cost' installations anticipate the outcome and adjust their bids even in a perfectly competitive setting in order to receive the clearing price. If, for example, due to uncertainty they are not able to anticipate the results, they might bid closer to their true costs, limiting infra-marginal rents, but might also bid too high, reducing the efficiency of the outcome. However, the auction data used for this study provides empirical evidence towards the theory that bidders can anticipate the auction results since the range of bids observed is lower than the cost distribution of participating technologies. The total amount awarded in the multi-technology auctions is determined by the sum of the volumes awarded in the technology-specific auctions.

Award Mechanism: Besides the investment support for energy efficiency measures, we consider three possible support mechanisms for operational aid: Fixed premiums, sliding premiums and CfDs, since those were used in the auctions analysed in the previous section. While the bids for fixed premiums can be directly observed from the data[138], the support level under sliding premiums and CfDs depends on the expectations about future market values, emission intensities and curtailment. Specifically, the effective bid for installation *i* under a sliding premium scheme is calculated using the following formula based on the installation's cost profile:

$$Effective\ Bid_{it} = \sum_{t} (max((Cost_{it} - MarketValue_{i,t}), 0) + ETS\ Price\ Compoent_{it}) * Production_{i,t}$$

The effective bid functions for other support mechanisms are simplified versions of this equation and are presented in the annex.

To make bids comparable, the support level is then converted to Euro per mitigated tonne of CO_2 by dividing the bid per MWh by the technology, country and time specific emission intensity and production volume. The auction mechanism then selects the technologies based on the lowest Euro per tonne of CO_2 metric available to meet the mitigation demand. Subsequently, the support paid to each installation is calculated by replacing the $Cost_{it}$ variable from the effective bid equation with the clearing price from the auction.

In order to have a reference case for our analysis, we use the same model to analyse the cost-effectiveness of technology-specific auctions. In this analysis the same mechanism is used as described before. However, the mechanism is run separately for each technology. In this case also technology-specific rules such as the reference yield model are possible and partly reflected in the auction clearing mechanism. The partial approximation of the reference yield model in the simulation adjusts payments of wind turbines by their location, and thus price-discriminates, but assumes that allocative inefficiencies from awarding support to wind turbines in wind-poor as compared to wind-rich locations are limited.[139] Further benefits of the reference yield model such as an increased competitive pressure between different locations and steady project pipeline for wind project developers (Deutsche WindGuard, 2019) are also not considered in this analysis. For an overview of the assumptions and description of the specific auction mechanism used in each analysis see Annex 2.4.5. A possible extension of the multi-technology auction is the introduction of technology-specific price caps which we consider in a sensitivity analysis.

[138] For technologies that are supported using a fixed premium scheme, we do not use cost information but instead directly model the distribution of bids.

[139] The extent of inefficiencies introduced by the reference yield model is being debated in the literature. Initially it was argued that the reference yield model would not lead to allocational inefficiencies (Navigant, 2019) while recent studies have found some inefficiencies do exist due to the successful bidding of market participants at lower quality locations (Navigant (2019), Deutsche WindGuard (2019)). In general, the reference yield model should not have any effect on the allocation of successful bids in years where the auctions are undersubscribed as was the case in 2019.

Evaluation: In order to evaluate the auction results, we calculate the technology-specific and overall mitigation costs and analyse the technologies chosen in each setting.

1.3.3 Dynamic simulation of broader tenders

Multi-technology and technology-specific support mechanisms could differ in their longer-term implications (see Section 1.2.4 for a discussion of the effects).

We therefore extend the developed static auction model (described in the previous section, which in turn builds on the cost-effectiveness methodology), to a dynamic setting over the time horizon from 2020 to 2030[140]. We investigate two types of dynamic effects:

- Limited cost-effective renewable energy technology potentials;
- Supply chain constraints leading to increased costs in case of strongly varying yearly demand levels.

First, to a varying degree EU member states have limited potentials for renewable energy technologies, which differ not only on technical grounds, but especially if environmental, social and political constraints are considered (Ruiz et. al., 2019). Furthermore, even within technologies, potentials are of varying cost-effectiveness (cf. McKenna et. al., 2014), e.g. due to variations in wind speeds and solar irradiation. This has two implications. First, as potentials are exhausted and more expensive sites need to be utilised, former cheap technologies may lose competitiveness, and relatively more expensive technologies may need to be built. Second, depending on the level of electrification of other energy demands, cost-effective potentials may thus be limited and may need to be largely exhausted to reach climate goals. Thus, the limit on cost-effective renewable energy potentials may be necessary to consider in a dynamic setting.

Second, (unexpected) changes in demand levels can have a negative impact on supply chains, as capacities need to be built up and maintained to deliver project installations. Such supply chains can be bottlenecks for the expansion of technologies (Pulsen & Lema, 2017). These not only encompass the production of the technologies themselves, but also local elements, such as planning, installation and operation (cf. JRC, 2017). As multi-technology tenders may result in stop-and-go extension of technologies (Kitzing et. al., 2019), this is a relevant effect to consider.

On the other hand, existing effects from the static simulation continue to be part of the dynamic simulation, but the timing of installations may impact their relative importance. Thus, the following effects can be observed in the dynamic model:

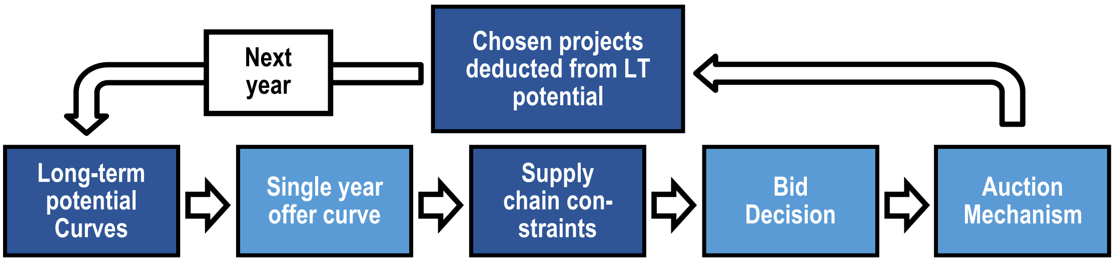
- Shift to cheaper technologies decreases the cost of multi-technology (MT) tenders (constrained by limited RES potential in the dynamic case);
- Shift of the utilisation of more expensive technology to the future decreases cost of multi-technology tenders (via discounting);
- Less stable demand for individual technologies (especially costlier technologies at the margin of being excepted) increases the cost of multi-technology tenders due to mark-ups at times of demand increases.

The model does not endogenously account for other relevant dynamic effects such as dynamic learning effects and dynamic effects on market values and system integration costs, depending on which technology mix is installed.

Figure 3 depicts the basic model set-up. The model builds on the static simulation (depicted in darker boxes) and extends it to a multi-year analysis.

[140] Start of 2030, thus auctions conducted in 2029.

Figure 3: Model set-up of dynamic analysis (dark blue boxes mark additional parts in dynamic model as compared to static simulation)



Source: DIW Berlin.

To approximate the longer-term potential for different technologies, we consider the difference of installed capacities between 2020 and 2030 of the PRIMES reference scenario[141] and multiply it with an excess potential factor that linearly extrapolates[142] the cost potential curve. In the base line scenario this excess potential factor is set to 20% and varied in the sensitivity analysis allowing to investigate the impact of the amount of potential, as compared to the policy ambition. Each year, a fixed percentage (base case 30%) of the longer-term potential is offered in the auctions (equally drawn from the overall potential, to represent (re-) development and permitting processes, and extended analysis is shown in Annex 4.5). Successful bids are assumed to be realised and therefore deduced from the longer-term potential remaining for the subsequent years. In the dynamic simulation, only a simplified auction is depicted which does not include the partial approximation of reference yield model.

If the demand for a specific technology exceeds the average installation volume of the preceding 5 years, then capacities along the supply chain may be stretched and costs may increase (no absolute limit exists on installations in the model from the supply chain). The calibration of the mark-ups is taken from an analysis on the price-capacity utilisation in the construction industry (BBSR, 2017, Appendix Annex 2.5).[143] This is to reflect the impact (unexpected) changes in demand levels can have on supply chains, which can be bottlenecks for expansion of technologies (Pulsen & Lema, 2017). Over time this effect decreases as capacity along the supply chain is built up. In line with the previous assumptions on the auction mechanism, we assume complete information. Market participants anticipate the auction results and mark-up their bids to reflect the supply chain constraints.

1.4 Case studies: results

1.4.1 Cost-effectiveness of selected schemes

The results of the assessment of cost-effectiveness of the different schemes are presented below. Since our measure of cost-effectiveness also represents the (carbon) mitigation costs of the supported technologies (as explained in section 1.3.1), we will refer to the latter term in the following.

Figure 4 presents the weighted average of the carbon mitigation costs of all considered auctions or support years. For the administratively supported CHP installations in Germany and Poland, the mitigation costs were calculated for various representative cases, of which the most and the least costly cases are indicated in Figure 4 (in darker/brighter colour). More detailed results including differences between mitigation costs between different years, auctions or cases are presented in Annex 3.1 along with a sensitivity analysis and a breakdown of mitigation costs into ETS price component and direct support.

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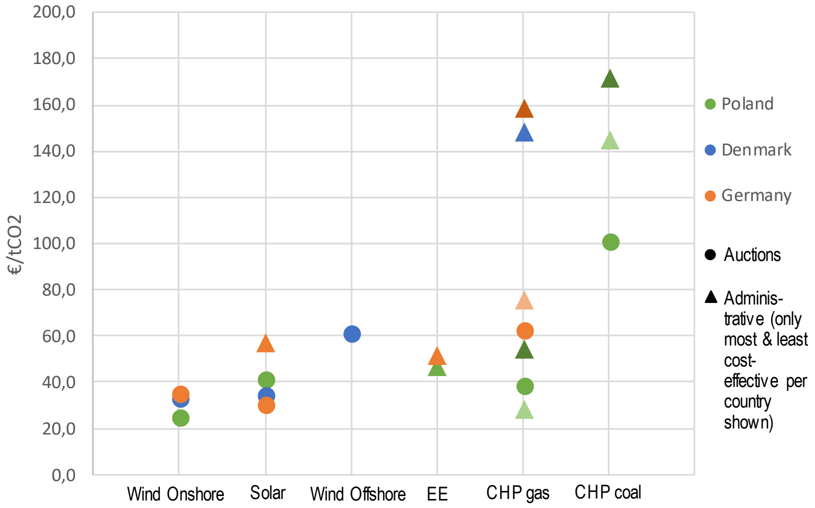
[141] This is a net difference in installed capacities, and thus underestimates the gross installations needed due to retirement of old installations. It also implicitly groups together auctioned and administratively supported technologies).
[142] We linearly extrapolate the cost potential curves beyond the defined PRIMES potential.
[143] The baseline are the flat installation levels in the technology specific case, as these are announced policy goals, and are thus expected by market participants.

Figure 4: Cost-effectiveness (or carbon mitigation costs) of the considered schemes by technology and country



Source: DIW Berlin.

Overall, results indicate that technologies other than CHPs are characterised by similar carbon mitigation costs. For CHPs, the results are mixed, as the mitigation costs of installations supported through auctions as well as some cases of administratively supported plants are comparable to that of the other technologies, but other administratively supported CHPs are shown to have significantly higher costs per tonne of CO_2 avoided (i.e. are less cost-effective). Differences within technologies are mainly driven by different emission factors of displaced electricity and heat generation (compare emission factors in Annex 2.3), support instruments and awarded levels of support.

For onshore wind, auctions in Poland achieved the lowest mitigation costs due to higher emission factors of electricity and heat generation and because relatively low strike prices for the awarded CfDs lead to a revenue for the state instead of aid over the lifetime of the plant in the considered scenario underlying the cost-effectiveness calculation[144]. As a result, the effective support is equal to the ETS price component less the revenue for the State resulting from the CfDs. Results for onshore wind in Germany and Denmark are more similar, although the support payments in Germany make up a larger share of the effective support compared to Denmark, where very low fixed premia were awarded. Differences between auctions and years are significant for Germany, as undersubscription in 2018 and 2019 led to relatively high awarded support levels, whereas awarded sliding premia were lower in 2017 thanks to higher competition[145].

For solar installations, auctions in Poland are characterised by higher mitigation costs than the ones for onshore wind due to higher awarded support levels in the auctions for small installations, where solar was mostly awarded support (i.e. overall mostly small installations were supported). Similarly, the mitigation costs for administratively supported installations in Germany are significantly higher than for the auctions since only small installations (<0.75 MW) were awarded and support levels for these installations are typically higher. Otherwise differences between the mitigation costs of solar auctions in Denmark are very low and in Germany, the 2018 auctions achieved slightly lower costs per tonne of CO_2 avoided due to lower awarded support levels.

[144] This is not the case for onshore wind installations which were awarded support in the auctions for small installations (<1 MW), since the awarded strike prices were higher. The awarded volume of onshore wind in these auctions was, however, very low.
[145] It should be noted though, that the actually realised cost effectiveness of the 2017 may only be seen in the long run, as the circumstances of the 2017 auctions with special conditions for citizen projects (" Bürgerenergieprojekte"), which include less stringent prequalification criteria and longer realisation periods, are not comparable to the following years.

While the mitigation costs over the weighted average of the three considered offshore wind auctions in Denmark are relatively high at 60 €/tCO_2, differences between the auctions are significant, with the 2015 auction achieving mitigation costs of around 100 €/tCO_2 and the 2016 auctions around 40 €/tCO_2. This is because a much higher strike price for the CfD was awarded in the 2015 auction compared to the 2016 auctions.

For the energy efficiency scheme in Germany, the estimated carbon mitigation costs are at about 50 €/tCO_2, which is moderately higher than the results for the RES support schemes. Differences between the tender years are relatively low with the exception of 2016, where significantly lower mitigation costs were achieved.[146] Although we assumed the same spending per MWh of electricity saved for energy efficiency measures in Poland as in Germany due to lack of data, the mitigation costs for Poland are slightly lower as a result of higher emission factors and hence mitigated emissions in the electricity sector.

Considering the auctions for CHP support in Poland and Germany, the achieved carbon mitigation costs are notably lower for Poland compared to Germany, which is the result of lower levels of awarded fixed premia and, again, higher emission factors of electricity and heat in Poland. For Denmark, on the other hand, the mitigation costs of the administratively supported CHPs are significantly higher due to lower mitigated emissions in the electricity and heat sector of Denmark.

Results for the carbon mitigation costs of the different cases of administrative support for CHP in Germany and Poland differ greatly. In Germany, mitigation costs are higher for smaller plants since support levels are higher for plants with smaller capacities. In addition, retrofitted plants are characterised by higher mitigation costs compared to new plants. This is because the average displaced emissions from heat generation over the support duration of retrofitted plants (15,000 full load hours) are significantly lower than the average over the support duration of new plants (30,000 full load hours; compare Annex 2.3).[147] For Poland, mitigation costs are relatively similar (below 60 €/tCO_2) between cases of gas-fired installations, whereas coal-fired installations are shown to have significantly higher costs (above 140 €) per tonne of CO_2 avoided due to higher generated emissions. Similarly, gas-fired installations supported in the auction achieve significantly lower mitigation costs of around 40 €/tCO_2 than the coal-fired installations that were assumed to have been awarded support in the auctions (around 100 €/tCO_2).[148] It should be noted however, that net mitigated emissions of coal-fired CHPs are only positive for Poland, where the electricity and heat generation remains (even in the considered energy scenario) relatively dominated by coal and hence even coal-fired CHPs achieve a carbon mitigation due to their higher efficiency compared to separate generation of electricity and heat.[149] Whether coal-fired CHP plants achieve carbon mitigation at all is therefore highly dependent on the future level of coal-fired generation in the Polish energy system, which is relatively high in the underlying PRIMES scenario that does not include the increase of ambition for 2030 targets yet (see Annex 2.3 for projected emission factors).

[146] One possible interpretation of this is that as this was the first year of the pilot scheme, the most cost-effective schemes may have participated first, while less cost effective schemes participated in later years.
[147] While the baseline assumption is that only gas-fired installations were supported in the German CHP scheme, we also estimated the mitigation costs for a representative administratively oil-fired installation: a new installation with a capacity of about 1 MW achieves mitigation costs of 196 €/tCO_2 in the reference scenario, which is about 100 €/tCO_2 higher compared to the same installation fired by natural gas. This result is very sensitive to the assumed efficiency however, as e.g. a lower assumed efficiency of 75% (compared to 81% in the reference scenario) increases mitigation costs to about 300 €/tCO_2.
[148] Due to lack of data, we assumed that 20% of the support volume in the Polish CHP auction was awarded to coal-fired installations and the remaining volume to gas-fired installations (see Annex 3.1).
[149] Even in e.g. 2030, coal and lignite still account for 92% of fossil fuel input in both electricity generation and district heating units in the PRIMES Ref 2020 scenario. As a result, emission factors of fossil electricity and heat generation remain at high levels of 0.85 and 0.39 tCO_2/MWh in 2030, respectively. Compared to these emission intensities, even coal-fired CHPs perform slightly better in terms of emissions since they are characterised by a higher efficiency. E.g. a coal-fired CHP with an overall efficiency of 81%, an electric capacity of 1 MW and a thermal capacity of 2.5 MW generates about 1.47 tCO_2 per (full load) hour, whereas in total 1.83 tCO_2 are avoided from separate generation of 1 MWh of electricity and 2.5 MWh of heat (see Annex 2.2 for detailed methodology and Annex 2.3 for data and assumptions).

Results are robust to variations of many of the underlying assumptions and scenarios, as shown in a detailed sensitivity analysis in Annex 3.2. Variations of the projected curtailment rate (increase to 5%/20% compared to 10% in the reference scenario) do not have a large impact, as it only gradually increases over time and thus mainly affects later years of the evaluation. This also applies to a variation of the SMNE (assumed to be 2 times the curtailment rate) and the assumption of current levels of grid-related curtailment for onshore wind in Germany. Similarly, a variation of market value projections only has a moderate impact for RES technologies supported by sliding premia or CfDs, as they also only gradually decrease over time.

In contrast, an increase of the social discount rate to future costs from 2% to 5% leads to a significant decline of carbon mitigation costs for all technologies (e.g. about 30% to 40% for onshore wind across countries; lower impact for energy efficiency since support granted as investment aid). It should be noted, however, that we deduce the historic bid prices (i.e. support levels) from the empirical analysis. These bids reflect the rate of return required by private investors, which is not varied in our analysis. For this reason, we also keep the award mechanism fixed to avoid the need to model changes for the financing costs of private investors.

For Denmark and Germany, the assumption of the heat displacement mix (assuming average mix (incl. biomass) displaced instead of fossil mix) has a large impact on the carbon mitigation costs of CHPs. While for Germany, mitigation costs increase by more than 100% to about 140 €/tCO_2 for the CHP auctions if the average mix is assumed to be displaced, the Danish CHP support leads to no carbon mitigation at all under this assumption, but an increase in emissions. Finally, the assumption on the efficiency of supported CHPs can have a significant impact on the mitigation costs, which becomes particularly relevant for cases where mitigation costs are relatively high due to low carbon mitigation (as for all (gas-fired) CHPs in Denmark, oil-fired CHPs in Germany or coal-fired CHPs in Poland).

Overall it should be noted that, despite comparable results, these were achieved with quite different policy instruments with large differences in payments (level and time profile), per scenario and support modality (investment and operational aid). Differences in support levels and hence cost-effectiveness are also driven by market dynamics, which e.g. determine project development pipelines and thus level of competition in auctions, and financing risks addressed by support instruments (e.g. CfD for RES in Poland, sliding premium in Germany).

Overall, the cost-effectiveness analysis showed that technologies other than CHP achieve similar carbon mitigation costs, despite very different policy instruments being in place. For CHP plants, results show wider differences in carbon mitigation costs cases, with e.g. oil- and coal-fired CHPs showing about 2 to 3 times higher mitigation costs than gas-fired plants, or even no carbon mitigation at all if biomass-fired heat is displaced or if coal is phased out more quickly than anticipated in the underlying scenario.

1.4.2 Static simulation of broader tenders

There are two effects that we expect to see in our analysis. On the one hand, we would expect that a *crowding out effect* takes place as less expensive technologies replace the higher-price options. This results in lower carbon mitigation costs of the multi-technology auction than of technology-specific auctions, if the volumes of technology-specific auctions are not optimized to achieve short-term minimal mitigation costs.

On the other hand, a multi-technology auction no longer allows for *technology-specific price discrimination*. This price discrimination might occur both between technologies (via separate tenders) and within a technology. First, in the multi-technology setting, the highest cost technology will determine the clearing price. This is true both in uniform (pay-as-clear), as well as pay-as-bid auctions, as in the first case the marginal bidder is price setting, and in the second case, bidders anticipate the clearing price and adjust their bids accordingly (cf. also the discussion in section 1.3.2). Thus, other (lower) cost technologies will be receiving excess profits compared to the technology-specific case. This can partially be addressed by the introduction of technology-specific price caps. However, the size of the effect will depend on the available potentials, the shape of the offer curve in respect to the auctioned volume. Second, we expect this effect to be especially pronounced in Germany, where the partial approximation of the reference yield model in the simulation allows not only for inter-technology, but for intra-technology price discrimination among onshore wind installations according to the verifiable quality of the local wind resource.

In total, the direction and size of the impact on carbon mitigation costs caused by the introduction of multi-technology auctions will depend on the following factors:

- *Volume of "high-price" technologies:* The larger the relative size of more expensive technology auctions is, the larger the cost decrease is when these are replaced by low-price options;
- *Excess capacity of "low-price" options:* The more excess capacity exists for the low-price technologies the more replacement can take place;
- *Price difference between technologies:* The larger the price difference is between technologies, the larger the cost decrease of multi-technology auctions will be.

In the following paragraphs we explore how these effects are represented in our empirical analysis.

Table 2: Overall cost-effectiveness (or carbon mitigation costs) in €/tCO_2

	Denmark, 2018	Denmark, 2019	Germany, 2017	Germany, 2018	Germany, 2019	Poland, 2019
Multi-Tech.	57.98	60.06	33.80	35.55	37.14	24.37
Tech.-specific	62.13	64.39	32.22	37.69	35.28	25.98

Source: DIW Berlin.

Germany, 2017-2019[150]: In 2018 the simulated multi-technology auction achieves 6% lower mitigation costs. This is due to the replacement of a small share of the large volume of onshore wind as well as large shares of energy efficiency and CHP with PV. In the multi-technology setting there is a large volume of both wind and PV as well as a small additional capacity of energy efficiency projects being awarded support, while CHP is completely replaced.

For the 2017 and 2019 auctions, we find the technology-specific auctions achieve 5% lower mitigation costs, because the price discrimination effect dominates. In the multi-technology auction, all wind turbines are paid the same price while the technology-specific auctions allow for inter- and intra-technology price discrimination, so that the technology-specific auction has a better cost-effectiveness. This is mainly because the wind turbines at locations with better wind resources are paid a lower support under the partial approximation of the reference yield model. Thus, as allocative inefficiencies from selecting wind-poor over wind-rich locations are assumed to be limited in scale, the partial approximation of the reference yield model leads to lower mitigation costs due to the effects of price discrimination. In Annex 2.4.2 we present an extended discussion of the implementation and effects of the reference yield model.

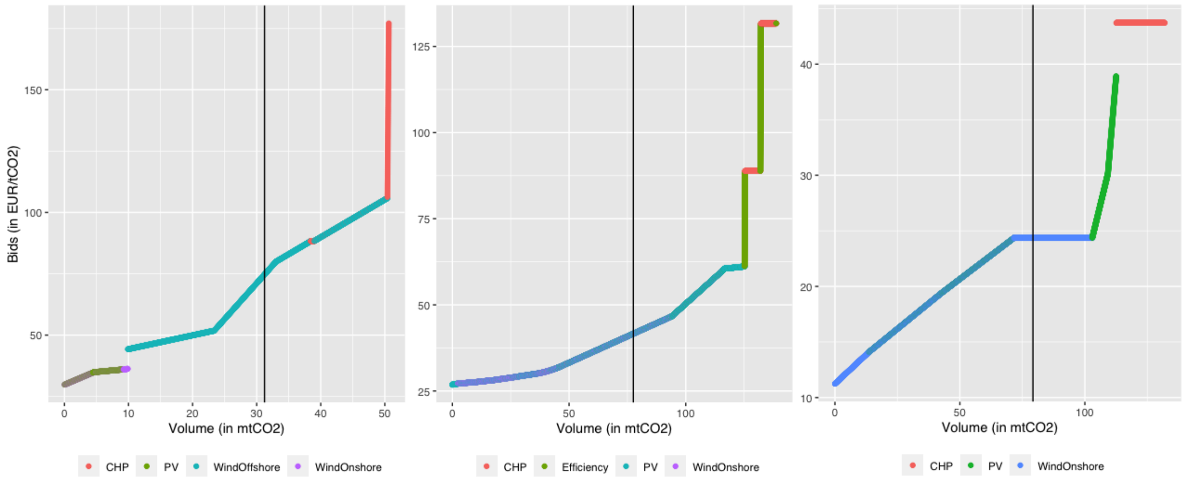
Denmark, 2018-2019: For the Danish auctions, we find that the multi-technology auction leads to a cost decrease of approximately 7% in both years. In the absence of intra-technology price discrimination and due to a larger share of more costly technologies (CHP and offshore), we see a larger decrease in costs than we saw in Germany. However, due to the very large volume of offshore wind and a relatively small available volume of PV and onshore wind, a large quantity of offshore wind is still chosen in the multi-technology auction, as can be seen in Figure 5.

Poland, 2019: Similarly, we can see that in the Polish case the multi-technology auction leads to 6% lower carbon mitigation costs. A special case of the Polish scenario is a clear

150 The results for the 2017 auctions in Germany have to be taken with a caveat, as a large number of local "Buergerenergieprojekte" were participating in the auctions under special requirements. They achieved unusually low prices but also saw lower completion rates.

stacking of technology prices: Onshore wind represents the cheapest (and largest) potential in our analysis, followed by the more expensive PV potential. The CHP options are clearly more expensive than the renewable options.

Figure 5: Offer Curves for 2019 in Denmark, Germany and Poland



Source: DIW Berlin.

Thus, the multi-technology auction leads to lower carbon mitigation costs with the exception of Germany. To explore the role that the reference yield model plays in the German results, we modelled the technology-specific auction with and without the correction for wind classes. The detailed results can be found in Annex 4. In general, we find that in the absence of the reference yield model, the technology-specific auction has higher costs. This indicates that the German results are in fact driven by the intra-technology price discrimination.

An extension of the multi-technology auction is the introduction of price caps to prevent installations from receiving windfall profits when higher price technologies are price setting. We implement this extension as a sensitivity analysis. The introduction of price-caps in multi-technology settings has two possible effects, that depend on the structure of the offer curve (and the price differentials of technologies) and on the level of the price caps:

- *Limiting windfall profits:* Price caps can limit windfall profits by re-introducing an element of price discrimination for the "cheaper" technology options. This should lead to lower mitigation costs since the price cap, rather than the most expensive bid of all technologies, becomes price setting for the "cheaper" technologies. Thus, this effect is larger the more expensive the price setting technology is as compared to other participating technologies.
- *Limiting cheap technology potentials:* The price cap leads to more expensive installations being awarded support if it limits the available potential of the low-cost technology options[151]. This is a detrimental effect on technology costs.

In general, multi-technology auctions with technology-specific price caps preserves some benefits of the impact that low-cost technologies can have on the higher cost alternatives and avoid the need for estimating and setting demand specifically for each lower cost technology. However, the price pressure on more expensive technologies may be somewhat reduced by the price caps which will tend to limit participation.

In Annex 4.3 we present the effect of the introduction of price caps within our model. The price caps are modelled as 110% of the price resulting from the technology-specific case. In Denmark the price caps have the desired effect due to higher cost differences in the chosen technologies in the multi-technology setting and the fact that the entire "cheap" potential is chosen in both cases. The annex offers a deeper discussion of both effects. In

[151] As many technologies have a distribution of cost potentials, some limitation on the potentials will be the usual case.

Poland, the price caps have no effect due to the specific shape of the supply curve within our model. In contrast, for the German case we find that the analysed price cap would have led to an increase in mitigation costs. Rather than prevent windfall profits, it would have shifted the auction results towards more expensive technologies, while not replicating the price discrimination taking place for different wind producers as in the technology-specific case with the partial approximation of the reference yield model.

Overall, the static model indicates that a multi-technology setting leads to lower carbon mitigation costs in RES auctions. These findings are in line with the claims of Navigant (2019) for the German case. However, the same caveats apply to the limitations of a static setting. A static setting does not consider effects such as system integration costs, learning rates or capacity constraints. Additionally, which technology is chosen in the multi-technology auction highly depends on the parameters chosen to calculate emission savings. Thus, there is additional complexity in designing multi-technology tenders. All of these might lead to higher mitigation costs and electricity prices when only a small set of technologies is supported in the multi-technology auction setting. In the following section, we try to capture some of these effects by considering a dynamic extension of the simulation model.

To conclude, the static simulation shows that multi-technology tenders lead to lower carbon mitigation costs in Denmark and Poland of 7% and 6% respectively, as well as 6% in one out of three years in Germany. Conversely, due to the price discrimination of the partial approximation of the reference yield model in Germany, which pays wind producers in better locations less support, technology-specific tenders have 6% lower carbon mitigation costs than the multi-technology case in the remaining two investigated years. As discussed before we assume allocative inefficiencies leading to a selection of wind-poor over wind-rich locations are limited.

Price caps for specific technologies in multi-technology tenders can reduce windfall profits, and do so in the Danish case, where a price cap set at 110% of the respective clearing price in the technology-specific tender leads to 9% lower carbon mitigation cost than in the multi-technology case without price caps. However, the simulation for Germany illustrated a potential risk from excluding the more expensive part of the potential of less costly technologies, which may still have lower carbon mitigation costs than the more expensive technologies. In this case, overall carbon mitigation costs increase.

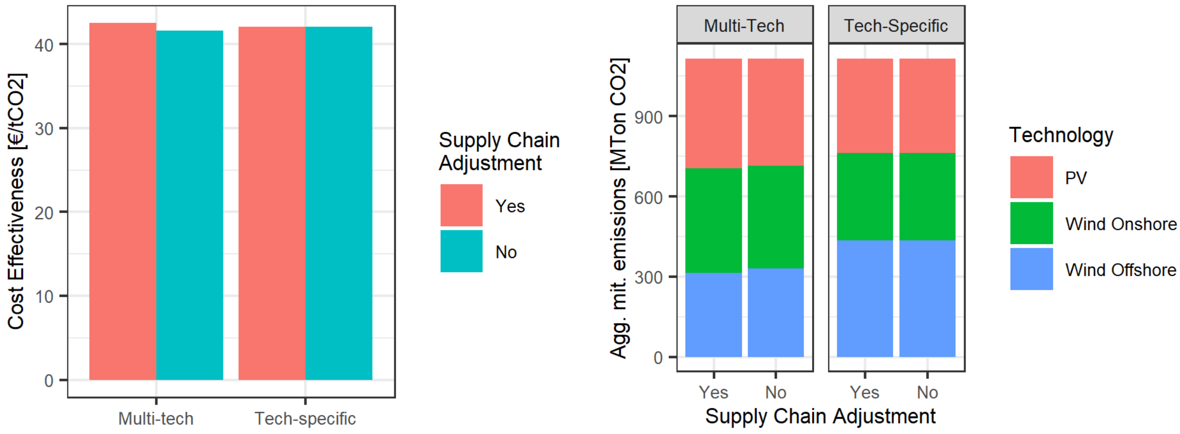
1.4.3 Dynamic simulation of broader tenders

The dynamic simulation is comparing separate onshore wind, PV and offshore wind auctions in Germany with a joint broader tender for the period of 2020 to 2030. In the dynamic auction offshore wind replaces the energy efficiency and CHP potentials due to the availability of comparable data on offshore resource potentials in the Primes reference scenario. This allows for an analysis of the difference between technology-specific and multi-technology auctions in the presence of a technology with moderately higher mitigation costs (here: offshore wind). In the following the results from this analysis are presented. Four cases are distinguished: one level is the distinction between multi-technology auction and technology-specific auctions, and the other whether the supply chain adjustment is applied or not (i.e. whether or not capacity constraints lead to cost mark-ups).

If supply chain constraints are ignored, in the case of 20% excess capacity multi-technology tenders have around 1% lower mitigation costs (without accounting for demand variation impacts on the supply chain). Considering supply chain effects, the multi-technology case has around 1% higher mitigation costs than technology-specific case.[152]

[152] There is no difference between the technology specific scenarios as they start out and maintain the same installation levels.

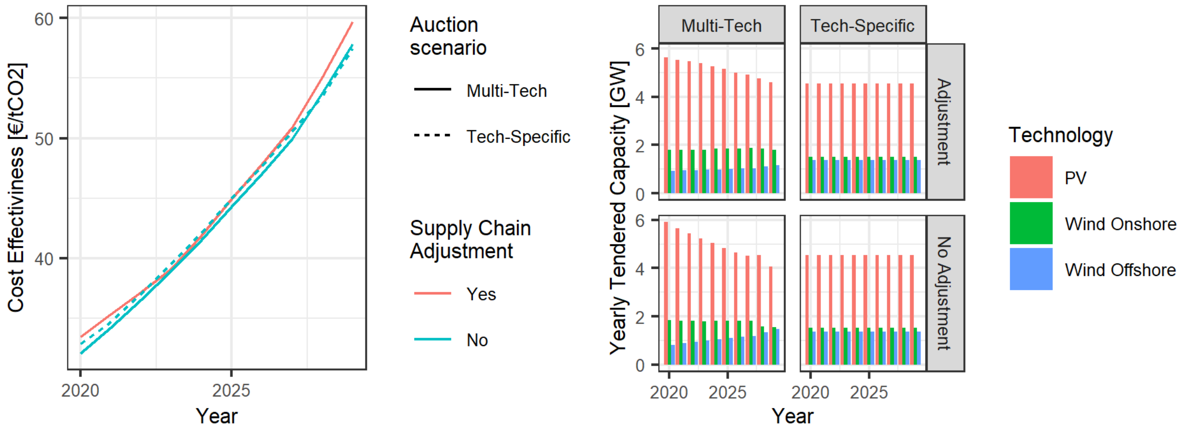
Figure 6: Cost-effectiveness and mitigated CO_2 emissions by technology



Source: DIW Berlin.

Both with and without supply chain constraints the multi-technology auctions result in higher shares of PV and onshore wind as compared to the more expensive offshore wind that is installed to a higher degree in the technology-specific case.

Figure 7: Cost-effectiveness and mitigated CO_2 emissions by technology over time



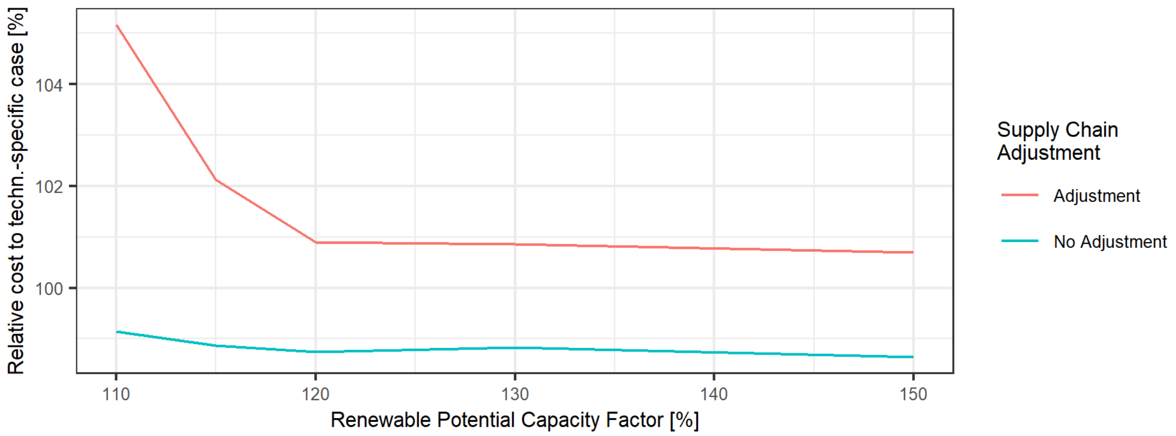
Source: DIW Berlin.

As compared to a static scenario (with no partial approximation of the reference yield model), all scenarios have higher levels of carbon mitigation cost of around 42 €/tCO_2 over the simulation horizon. There are several reasons for the larger similarity of levels of cost-effectiveness, and larger similarity of technologies winning in the tenders in the ten-year simulation period:

- The longer-term cost-potential curves of the investigated technologies are overlapping from the start of the simulation;
- As cheaper potentials are chosen first, the overall cheaper technologies get closer on average in cost to the other technologies;
- Potentials of technologies are constrained, thus also the more expensive technologies are implemented.

The results and relative cost ordering of scenarios is relatively robust to a sensitivity analysis of the excess potential of the long-term potential (cf. Figure 8) and the yearly offer-percentage. Overall higher excess potentials lead to smaller benefits of technology-specific tenders, as technology-mixes with lower mitigation costs can be chosen from the larger potential and be installed earlier, and tighter potentials to larger benefits, as capacity constraints lead to larger markups in the later years of the simulation (cf. Annex 4).

Figure 8: Impact of available potentials on cost of multi-technology tenders, as compared to technology-specific tenders



Source: DIW Berlin.

To conclude, the dynamic simulation shows that in the presence of limited renewable potentials, and supply chain constraints that lead to cost increases, technology-specific tenders can outperform multi-technology tenders by around 1%, due to a more stable demand for individual technologies. In the absence of supply chain constraints, multi-technology tenders continue to outperform technology-specific tenders by around 1%.

1.5 Conclusions

The assessment of the proportionality of the aid for environmental protection schemes requires evaluating both the cost of the support and the environmental benefits they will achieve. The measurement of cost-effectiveness attempts to collapse both benefits and costs into a single dimension. The literature review shows that cost-effectiveness for decarbonisation schemes (including those for renewables and energy efficiency) is measured as the ratio of the cost of the support net of monetisable benefits and the CO_2 or CO_2 equivalent emissions reductions (€/tCO_2 or €/tCO_2e). This helps identify and prioritise projects that deliver environmental protection at lower costs and avoid subsidies for pro-jects that are less worthwhile. The literature shows that Member States are increasingly relying on the cost-effectiveness assessment for decarbonisation schemes, thereby mov-ing away from approaches based on EUR per unit of energy produced, which ignores the contribution of the measures being aided to the environmental protection objectives.

The literature review stresses that there are various caveats to bear in mind when measuring cost-effectiveness for decarbonisation schemes. CO_2 or CO_2 equivalent emission reductions may not be limited to the geographic market targeted by the measure and instead include foreign carbon offset due to green electricity exports. The estimate of emissions reductions and of the abatement costs may also need to properly take into ac-count the interaction with overlapping decarbonisation measures, such as the EU ETS, and the related effect on the EU wide CO_2 emission. The literature also urges for the need to take into account environmental impacts other than CO_2 emissions, and namely, intersec-toral spillovers, learning-by-doing effects, behavioural responses, the impact on biodiver-sity and the ecosystem. The appraisal of learning-by-doing effects would require a long-term assessment of the cost-effectiveness; this may however carry the risk of selecting a new technology (with potential of large costs reduction in the long-term) that might be-come rapidly outdated. On the other hand, a cost-effective CO_2 emissions mitigation in the short term may not allow to reach long-term emission targets at the lowest possible costs.

By stimulating the competition among potential beneficiaries, the use of competitive bidding procedures may lead to cost discovery and help limit the aid to the minimum needed. How auctions minimise support cost is however dependent on their design. The review identifies at least four elements which may influence participation in the auction, competition between potential beneficiaries and in turn bidding behaviour: the pricing rule (pay-as-bid vs pay-as-clear), the format (static, dynamic or hybrid), the existence of prequalification criteria and the scoring rules. Each element can have some drawbacks and policymakers should carefully design auctions to mitigate them. For instance, while the pay-as-bid pricing rule enhances rent seeking behaviour, the use of sealed bid auctions and/or reserve prices may help mitigate such risk. The academic research also stresses the trade-off between technology-neutral (open to all available technologies) and technology-specific (which promote a selected technology) tenders. Technology-neutral tenders may reduce the cost of support, but may also crowd-out the most expensive technologies and generate windfall profits for the least expensive technologies. Technology-specific tenders may help foster technology diversity, but they rely on the ability of policymakers to identify the right technology to promote. Multi-criteria auctions may help express policymakers' preferences for nurturing promising new technologies, promoting small players or achieving wider environmental benefits (e.g. minimum impact on biodiversity). However, the academic research stresses that multi-criteria auctions may lead to inefficient outcomes when they do not perfectly express the trade-offs among several objectives in the scoring rule. This does not imply that single criteria auctions are more efficient: while they are simpler in some ways, a score based on a single criterion also risks failing to address trade-offs and leading to inefficient outcomes. The use of tendering has proved to be successful to support decarbonisation measures other than renewable generation, such as the deployment of CHP plants and energy efficiency programmes. CCfDs have also re-cently played a major role in the discussion on the most appropriate policy options to promote investments in low-carbon technologies, both in the power and the industrial sec-tors. Recent papers stress that CCfDs could help reducing financing costs, as emission reduction projects may not be mature enough to be financed through ETS and go beyond the scale of R&D funding.

Study item 1 discusses whether broadening the aid scheme to multiple sectors and technologies, which contribute to similar environmental objectives, may also help to keep the cost of support to a minimum. To help the Commission evaluate the merits of broadening schemes, at least for decarbonisation supports, the study relies on both a literature review and case studies which simulates the costs and benefits of broader tendering. The literature review shows that decarbonisation schemes open to multiple technologies and sectors help deliver savings compared to narrower policies (SDE+). The achievement of cost savings, however, may depend on the design of the scheme and the disparity of eligible projects: the Dutch scheme SDE+ and the Swedish scheme Klimatklivet have indeed achieved opposite results. In particular, Klimatklivet has shown that it may be difficult to find a method to fairly compare the costs and the environmental benefits of each technology and sector. In line with the findings of the academic research on technology-neutral tenders, the study shows that multi-technology schemes may be exposed to the risk of windfall profits (SDE+, which partially addresses this risk with technology-specific bid caps). Furthermore, by stimulating competition between potential beneficiaries, broader tenders may magnify the risk of underbidding: bidders may be tempted to offer lower prices (than those financially sustainable) to receive the support before the overall budget is exhausted (SDE+). Finally, such integrated schemes should be carefully designed to avoid undue restrictions to eligibility, by excluding cost-effective emission reduction options for which part of the investment is unviable.

The case studies (i) estimate the cost-effectiveness of selected RES support schemes, CHP support schemes and energy efficiency programmes for Denmark, Germany and Poland and (ii) simulate the cost savings that might have been achieved if Member States had used a single support mechanism based on a competitive bidding procedure to achieve the same level of environmental protection as that pursued by three individual programmes separately.

The cost-effectiveness analysis showed that overall technologies other than CHP achieve a similar carbon mitigation costs. This similar level of cost-effectiveness for the other technologies was achieved with a wide range of policy instruments with large differences in payment structure over time and support modality. For CHP plants, results show wide differences in mitigation costs between cases. Smaller gas CHP installations in Germany achieve up to 50% (new plants) or 85% (retrofitted) higher costs per tonne of CO2 avoided compared to larger gas CHP plants due to higher support levels, while oil- and coal-fired CHPs show about two to three times higher mitigation costs than gas-fired plants. In some cases (oil- and coal-fired plants, but also gas-fired in Denmark), the CHP support may not lead to any emission reductions if some biomass-fired heat is displaced or if coal is phased out more quickly than anticipated in the underlying scenario.

A common characteristic is that where within one technology both competitive tenders and administrative schemes were used, the administrative schemes were costlier; how-ever, this was often due to the smaller project sizes supported with administrative schemes to target additional policy goals or realise potentials otherwise not targeted (small-scale roof-top solar).

The differences within technologies and across countries are driven by emission factors of displaced electricity and heat generation, market dynamics (projects development in pipe-line at the time of the tender and thus level of competition), as well as the differences in financing risks addressed by support instruments.

The cost-effectiveness study also showed robustness to various input parameters, such as curtailment rates, and market values. However, other factors including efficiency lev-els for CHP plants have strong impacts on the relative cost-effectiveness of technologies. The overall level of cost-effectiveness for all technologies is impacted by discount rates, future assumed emission intensity of the energy system, and electricity prices. A compar-ison of cost-effectiveness does therefore require a coherent set of assumptions.

Finally, the cost-effectiveness study focussed exclusively on carbon mitigation as the en-vironmental benefit. However, as also stressed in the literature review, support schemes and technologies may have broader goals and impacts than those, such as impacts on biodiversity, resource efficiency, quality of air and water, and land use, as well as eco-nomic goals such as innovation, energy security and social acceptance.

The study also conducts a static counter-factual simulation, which assumes uniform pric-ing, perfect competition and information, and ignores dynamic effects, as well as other environmental and system impacts. For two observation years in Denmark and one ob-servation year in Poland, we find a reduction of carbon mitigation cost of approximately 6% with a multi-technology auction compared to the technology-specific case. For Ger-many, cost reductions of 6% in case of a multi-technology tenders were obtained only in one year, while in the other two observations years the multi-technology auction results in an increase of mitigation costs by 5-6%, assuming only a limited impact of allocative inef-ficiencies of choosing more costly wind locations. Generally, we find that two coun-teract-ing effects occur when transferring from a technology-specific to a multi-technology ten-der: A crowding-out effect of more expensive technologies (from a static perspective) and a price discrimination effect. In settings with a large degree of (intra- and inter-tech-nology) price discrimination in the technology-specific auction, the technology-specific ten-ders could result in lower mitigation costs than multi-technology tenders. In the cases it occurred in the simulation (i.e. in Germany), intra-technology price discrimination was applied, and allocative inefficiencies were limited.

Technology-specific price caps to limit inter-technology infra-marginal rents present in multi-technology tenders were investigated as well. In the Danish case, with more expen-sive offshore wind price setting, a multi-technology tender including such price caps leads to lower mitigation costs of around 9% (as compared to the multi-technology auction without price caps). However, the price caps can also lead to the exclusion of renewable potentials of more cost-efficient technologies and thus increase overall costs, approximat-ing the technology-specific case (observed in the German case study).

To assess the dynamic effects, we simulated a portfolio of onshore wind, PV and off-shore wind. We find that technology-specific auctions outperform multi-technology auc-tions by 1% if we consider repercussions from more variable demand for technology in-stallations on supply chains and if technology-specific resource potentials are limited. These effects lead to a 2% increase of costs of multi-technology tenders and are larger if technology potentials are further limited.

Next to the challenge of pursuing several environmental goals in a single tender, there are practical challenges of conducting joint tenders that could not be considered in the simu-lation study. The differences between underlying technologies have resulted in tai-lored policy implementations for different technologies by Member States and may create challenges for the design of a joint support mechanism. While it might be relatively straightforward to put different electricity generation technologies together, energy effi-ciency measures are often highly specific and tailored to institutional settings with differ-ent project lifetime, cost streams, way of financing and measurement of success in a standardised way. The simulation assumed that the same policies stay in place after the shift to multi-technology auctions. If policies are changed, however, this may impact in-centive structures, as well as financing conditions, e.g. a CO_2 hedge may be less effective in hedging against power price uncertainty, and hence result in higher risks and financing costs. If the unit of auction (e.g. €/tCO_2) differs from the unit of payment (and meas-urement, e.g. €/MWh), it also needs to be ensured that the incentives to reduce emis-sions are reflected in the payment mechanism, especially in operation.

Another challenge not considered in the simulation study is the creation of a level playing field between technologies, since many parameters have to be set (correctly) to account for different characteristics such as system impacts, risks and costs for development. While it is certainly beneficial and a step forward to include such impacts in scoring rules for multi-technology tenders if correctly approximated (e.g. via €/tCO_2 scoring), deter-mining these has a certain level of discretion in practice and has risks as wrongly set pa-rameters may lead to strong biases in the selection process. This does not only apply to the auctioning goal itself, but also pre-qualification conditions, realization times, meas-urements of success and other conditions. The more different the participating technolo-gies are the more difficult it is to avoid implicit biases between technologies. In technolo-gy-specific auctions the trade-offs between different environmental impacts, system ef-fects and other externalities naturally also exist, and need to be considered outside of the auction design.

2. Study Item 2: Investment and operating aid

2.1 Introduction

The ultimate objective of the work in this section of the report is to provide the Commission with data, analysis and expert judgement on the effects of awarding State aid either as investment aid or operating aid, so the Commission can conclude to what extent this distinction is still justified and to what extent compatibility rules for investment and operating aid should be aligned, in particular for environmentally friendly energy generation.

The evidence is focused on three main areas:

- A literature review on the distinction between operating aid and investment aid in the context of the EEAG;
- A detailed case study comparison of operating aid and investment aid across four GBER or approved EEAG schemes; and
- A set of hypothetical support schemes with their impact on steel, cement and fertilisers (represented by ammonia).

In the following three subsections our approach, methodology and findings for each of these areas is described including where appropriate, strategies for data collection and quantitative methodologies.

Overall, the conclusion from reviewing the literature is that, in the area of support for environmentally friendly energy production, evidence of effectiveness is more frequent for operating aid however effectiveness varied by instrument and sector. For example, grants and loans (both typically investment aid) had a positive effect on levels of investment highlighting that investment aid still has an important role within State aid.

The essentiality of the distinction may be less clear with respect to aid for environmentally friendly energy, given the nature of investment-focused achievement that is inherent in the green transition. The ultimate objective of much of the aid is to incentivise new investments on a massive scale, which can be facilitated either through investment or operating aid (or by a combination of both). Based mostly on a review of research evaluating energy-related projects, in practice, operating aid seems more frequently awarded, while investment aid capped at maximum aid intensities which can be too low fails to cover the increased costs of investment, though this incomplete support may be counter-balanced by various fiscal and pricing structures (e.g., when the price received for energy, even without a feed-in tariff, substantially exceeds the variable cost of production). Solutions have already been found for appropriately incentivising energy investments, with some new energy investments having aid levels bid down to zero. Zero bids could suggest that State support may be increasingly less necessary as investment costs decrease and buyer demand for renewable energy increase, though it may be that network costs are not paid for by the project developer in case of zero bids.

In practice, one may ask how schemes of environmental protection investment and operating aid incentivise investment and achieve expected benefits. Four energy related schemes are examined in detail to gain deeper understanding of the impacts of investment and operating aid for different types of technologies. These schemes include a PV electricity scheme granting investment aid, a biogas scheme granting operating and investment aid, a CHP scheme granting operating and investment aid and a high-energy-efficient natural gas cogeneration scheme granting operating aid. The solar electricity generation investment aid scheme is being discontinued due to the level of aid not making private profitability feasible. Operating aid support for PV in a comparator scheme experienced a major fluctuation in investment levels as administratively set operating aid failed to capture the rapidly decreasing investment costs of PV which caused an increase in investment when aid was high followed by a decrease in investment when support was lowered. Competitively set support levels appear to offer a solution to this problem by offering more accurate cost discovery.

The biogas scheme with operating aid and investment aid was found to be a relatively effective measure at securing investment in the expansion of biogas facilities; demonstrating that operating aid and investment aid can work in tandem with each other.

Non-financial barriers such as administrative burden and unclear or complex procedure were reported by stakeholders in both operating aid and investment aid schemes suggesting many issues may be scheme specific, not intrinsic to operating or investment aid schemes.

In contrast to energy generation, in which the transition to new technologies is well underway, industrial decarbonisation is still at an early stage. While industrial decarbonisation shares some of the complexities of energy decarbonisation, with many different technologies and costs, it differs to the extent that some industries can be much more economically decarbonised than others and that the outputs of industrial production in different industries are not generally substitutes for each other. Moreover, it is not clear that investments in industrial decarbonisation projects will result in a significant reduction in operating costs as was the case for energy generation transitioning from fossil fuel sources to PV, wind and water technologies with variable costs close to zero. The high margins on such PV, wind and water production, in the renewable energy generation sector, can counter-balance partial investment support, which is not equally the case for breakthrough CO_2-reducing industrial investments.

Comparisons between potential schemes for industrial decarbonisation suggest that (i) investment aid at a 40% of eligible costs (i.e. extra investment costs) will not achieve substantial incentives for large and expensive investments, and that much higher levels, up to 100% (or more), could be required when new technology variable costs are the same as under the prior technology (or increased); (ii) 100% support of the funding gap for new projects will substantially reduce potential investment losses related to more expensive new investment but risks doing so at high costs when managing authorities do not know appropriate cost levels, and (iii) carbon contracts for difference may offer a number of advantages, but also have risks. A particularly important trade-off on decarbonisation of specific industries against cost efficiency can be observed in the decision that would be made over whether to set prices of CCfD tenders within an industry or across industries. If CCfD tenders run across multiple industries, cost efficiency will be enhanced, but some industries, might likely achieve higher decarbonisation than others, possibly with ammonia decarbonising last of the three in rank order, though there may be differences in cost by technology within each category and also depend of the method chosen to determine CO_2 emission reductions. If the goal of the initial projects would be to develop demonstration technology, single industry tenders or 100% support of the funding gap for new projects may be appropriate, though these could be subject to lack of competition due to few potential providers in many Member States. By creating conditions in which projects covered by CCfD have advantages due to predictability of the CO_2 price, beneficiaries may have incentives to produce that do not necessarily reflect ongoing market price developments, much as production of energy with support may have contributed to over-supply at some moments (and negative energy prices).

2.2 Literature review on the distinction between operating aid and investment aid in the context of the EEAG

2.2.1 Introduction

The objective of this section is to summarise the results of the literature review on the distinction between operating aid and investment aid under the EU Guidelines on state aid for environmental protection and energy 2014-2020 (EEAG).

Under the EEAG aid can be awarded in two forms: investment aid and operating aid. Investment aid generally covers the upfront capital costs of an environmental protection or energy project (Van Hees, 2018) and is typically paid out as an ad hoc payment at the start of a project. Operating aid can be used to both offset the costs of investment over the lifetime of an energy project or to provide a project with ongoing operational support. Operating aid is typically directly related to output and therefore is paid out over a project’s lifetime.

Papers are reviewed under two broad criteria:

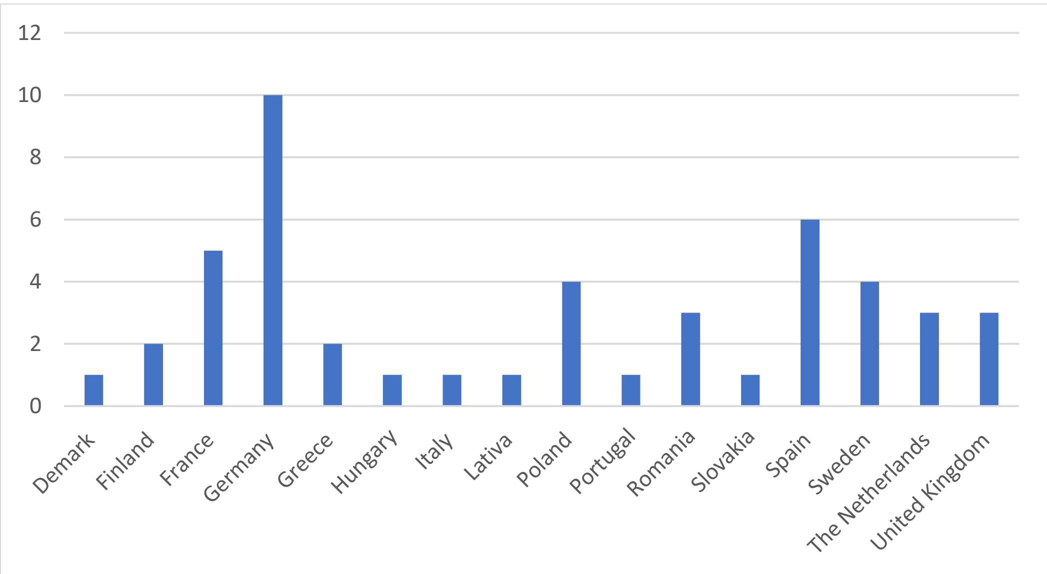
- **The effectiveness of operating aid and investment aid**: we examine the literature on the effectiveness of operating aid and investment aid. This includes effectiveness of securing investment for renewable energy and environmental protection projects, administrative effectiveness (e.g., does a particular type of operating aid or investment aid effect the level of administrative burden) and whether aid is necessary (e.g., does aid lead to free-riding effects).
- **The distortive effect operating aid and investment aid may have on energy markets**: we examine the literature on the circumstances which can cause operating aid or investment aid to have a distortive effect on energy markets (e.g., circumstances that can lead to low or negative prices) and possible solutions to distortive effects offered by the literature.

The review only includes papers with a strong European focus and substantive qualitative or quantitative analysis. Sources were compiled from survey papers and an initial literature review and subsequently expanded via reverse citation.

This review contains 172 relevant sources listed in Annex 6. The review includes aid awarded to various types of renewable energy producers, combined heat and power plants, nuclear and energy efficiency measures, low emission mobility, aid in the form of tax reliefs for energy consumers and sources discussing the distortive effect operating aid and investment aid may have on energy markets. Although the review predominately focuses on aid awarded to renewable energy and cogeneration producers some valid conclusions can still be drawn from the literature on other forms of environmental protection, additionally were possible we draw parallels across sectors. 135 sources meeting the above criteria address renewable energy producers and 8 sources address CHP producers.

The review includes 124 studies based on two or more Member States and 48 studies focused on a single Member State.[153] Figure 9 illustrates the range of Member States in the single category.

Figure 9: Member State-specific studies included in literature



Source: UEA, based on studies listed in Annex 6.

Both operating aid and investment aid can be awarded through a wide variety of instruments, some of which can by their nature only grant operating aid and some of which can function as operating or investment aid. Therefore, we also summarise conclusions on the

[153] For the purposes of this classification, a Member State is one that was a Member State for the time period of the data used in the study.

effectiveness of these different types of instruments. These can broadly then be aggregated to understand results on operating and investment aid, which are not typically analysed as classes.

Given the wide variety of instruments, broad technological scope of the EEAG and large range of Member States covered in this review, papers often reach different conclusions. Where applicable we identify these differences.

2.2.2 Effectiveness

Environmental protection and energy projects often have considerable capital costs and, therefore, have to secure substantial investment to commence operation (Kim and Park, 2016, Polzin et al., 2019).

Operating aid and investment aid offer two very different avenues to securing this investment. Investment aid supplements or replaces private capital costs. Operating aid allows investors to offset their investment over the lifetime of a project and in some circumstances also makes investment more attractive by mitigating a portion of operating costs. Where operating aid is fixed over the lifetime of a project it may potentially offer investors guaranteed returns over the lifetime of an investment (Wohlgemuth and Madlener, 2000).

172 sources were reviewed in a tabular analysis (see Annex 7) for findings on the effectiveness of measures at securing investment. The results of this review are summarised in Table 3 and provided in full in Annex 7. As some papers reviewed multiple instruments, 385 instances of analysis were identified. Of these 385 instances, 178 were positive (46%), 28 were negative (7%), 27 were mixed (6%) and 152 (40%) were inconclusive. Operating aid instruments were far more frequently found to be effective at securing investment than they were ineffective (141 effective, 16 ineffective). Investment aid instruments were also more frequently found to be effective at securing investment than they were ineffective (37 effective, 12 ineffective), however, significantly fewer instances of investment aid were observed (111 investment aid, 274 operating aid). There were also a high proportion of inconclusive results in this category (49% compared to 36%).

Operating aid and investment aid instruments were grouped into several broad categories, shown in Table 4. Feed-in tariffs were the category of operating aid most frequently found to have a positive effect (75 out of 107 instances, 70%). Grants were the category of investment aid most frequently found to have a positive effect (16 out of 44 instances, 37%).

Table 3: Effectiveness of Operating/Investment Aid measures

Type of Aid	Effectiveness of Measure at securing investment	Effectiveness of Type
Operating Aid	**-Feed-in Tariff** *-Positive* *(75 effective, 2 ineffective, 23 inconclusive, 7 mixed)* -**Feed-in Premium** - *Positive* *(18 effective, 0 ineffective, 12 inconclusive, 5 mixed)* -**PPA Auction** -*Limited Positive* *(12 effective, 0 ineffective, 12 inconclusive, 0 mixed)* -**Tax Credit** -*Limited Positive* *(20 effective, 6 ineffective, 19 inconclusive, 3 mixed)* -**Guarantee** -*Limited Positive* *(5 effective, 0 ineffective, 14 inconclusive, 1 mixed)* -**Green Certificates** -*Limited Mixed* *(11 effective, 8 ineffective, 18 inconclusive, 3 mixed)*	**Mostly Positive** *(141 effective, 16 ineffective, 98 inconclusive, 19 mixed)*
Investment Aid	**Grant** -*Limited Positive* *(16 effective, 3 ineffective, 21 inconclusive, 4 mixed)* -**Loan** -*Limited Positive* *(11 effective, 1 ineffective, 13 inconclusive, 1 mixed)* -**Investment Tax Credit** -*Limited Mixed* *(9 effective, 6 ineffective, 14 inconclusive, 1 mixed)* -**Direct Investment** -*Limited Mixed* *(1 effective, 2 ineffective, 6 inconclusive, 2 mixed)*	**Limited Positive** *(37 effective, 12 ineffective, 54 inconclusive, 8 mixed)*

Source: UEA.

Table 4: Instrument descriptions and categorisation

Category of Instruments	Description of Category
Price-based Support *(Necessarily Operating Aid)*	Price-based support instruments either provide operating support in addition to a market price (feed-in premiums) or provide remuneration instead of a market price (feed-in tariffs).
Certificate Schemes *(Necessarily Operating Aid)*	Certificate-based schemes require suppliers or customers of a product to hold certificates proving a proportion of their energy production or consumption has been produced from a particular source (for example renewable sources). These producers are issued with certificates, thus creating supply and demand.
Tax Credits and Investment Tax Credits *(Operating Aid or Investment Aid)*	Tax credits grant beneficiaries a reduction to their tax liability such as reductions to excise duties on electricity or VAT reductions.
Guarantees of Income *(Necessarily Operating Aid)*	These provide a guarantee of income to beneficiaries.
Grants and Loans *(Mostly Investment Aid)*	These measures provide investment aid to renewable energy or environmental protection projects, either through reducing the cost of private investment (direct investment and grants) or through offering preferential loans to reduce the cost of debt.

Source: UEA.

2.2.3 Price-based mechanisms: feed-in tariffs and premiums

Price-based instruments are by their nature operating aid as they award aid for each unit of energy produced. Feed-in tariffs (FITs) award aid at a set level, while feed-in premiums (FIPs) offer aid in addition to market prices. Price-based support can either be awarded through auction or can be administratively set.

The EEAG requires operating aid be awarded through a competitive, market-based process for energy producers over 500KW (3MW for offshore wind). Price-based aid is therefore mostly awarded through feed-in premiums; however, non-market-based operating aid can still be awarded for producers with a capacity of 500KW or less.

Righini and Gasperi (2019) found 21 out 29 Commission decisions on RES support schemes in 2017 and the first quarter of 2018 related to FIPs; however, despite this, FITs were the most widely studied price-based instrument within the literature review (107 instances to 35 instances), potentially because feed-in tariffs were frequently used before the EEAG.

FITs are often cited as being effective at stimulating investment as they eliminate private investors exposure to market forces and therefore shift risk premia away from investors (Polzin et al., 2019), they may also contribute to the commercialization of emerging technologies (Westner and Madlener, 2010). However, FITs are also found to be expensive (Bougette and Charlier, 2016), economically inefficient (Romano et al., 2017), hamper innovation for more mature technologies (Johnstone, 2010) and are a less effective tool for increasing capacity for mature markets (Romano et al., 2017) and technologies (Polzin, 2015).[154] Therefore they are often considered the least desirable form of price-based operating aid.

Polzin et al. (2015) posit investors prefer market-based instruments for mature technologies as these are less dependent on policy changes. This is supported by Criscuolo and Menon (2015) who found overgenerous FITs harm investor confidence as investors fear

[154] The literature also criticises feed-in tariffs for being highly distortive to markets. This is discussed separately in the price signals and market distortions section of this review.

these policies will be withdrawn. FITs may be particularly ineffective in periods of regulatory instability, as instability may increase concerns over their withdrawal. Del Rio et al. (2012) found regulatory stability important for increasing renewable capacity.

FIPs were mostly found to be effective at securing investment (18 positive, 0 negative, 12 inconclusive, 5 mixed), although, less effective than FITs (75 positive, 2 negative, 23 inconclusive, 7 mixed). FIPs provide less predictable income than FITs as a part of a producer's remuneration is subject to market forces (Haas et al., 2011). However, FIPs are generally favoured by policy makers as they are closer to full market integration (Hu et al., 2018).

A 2020 study by Alolo and Azevedo, suggests that although both FITs and FIPs lead to an increase in solar and wind capacity, the specifics of policies and market conditions (tariff prices, duration, degression rates[155], electricity prices, production costs and interest rate) were all found to play an important role in investment decisions. This highlights that although price-based support may have a positive effect on investment, design of these instruments is crucial.

Price-based operating aid is further supported by an evaluation of the Dutch SDE+ Scheme by Blom et al (2016) who found a small percentage of free riders (between 5%-15%) within the scheme. The scheme was also found to be necessary as projects that did not receive aid (due to budget exhaustion) mostly ran at a loss or a lower return than is customary in the energy sector. Additionally, the scheme was not found to be a significant administrative burden to beneficiaries.

Zuidema (2020) criticises price-based operating aid arguing operating aid for expensive mature technologies (such as solid-state biomass) may hamper reductions in overall renewable energy cost as price-based operating aid measures may 'lock in' aid for mature technologies at a higher level and disincentivise investment in less mature technologies.

'Locking in' aid at high levels can be of particular concern for some markets which might be moving towards a subsidy-free environment. For example, recent tenders in the Dutch offshore wind sector (Hollandse Kust Zuid 1 and 2) were won by zero-subsidy bids[156].

However, as price-based operating aid provides operational support over time in addition to supplementing investment costs, there are circumstances under which the support cannot be removed. For instance, Baltputis et al. (2018) find CHP FIP support necessary for the Latvian electricity market to function efficiently. Without FIP payments two large CHP plants would close, resulting in a substantial increase in the overall electricity price in Latvia. Additionally, Jääskeläinen et al. (2018) raises concerns that removing price-based operating aid for CHP in Finland could have future security of supply implications which could also lead to an increase in electricity prices.

One potential solution to 'lock in' is to design FIPs and FITs with reductions (or the potential for reductions) in support over time for existing producers in order to give granting authorities the power to reduce tariffs[157]. Another would be to limit the duration that producers can receive support to ensure that consumers are not paying for high levels of support indefinitely (del Rio, 2012).

As reducing tariffs over time may not always be possible, in some circumstances additional steps have to be taken to ensure that price-driven operating aid remains at appropriate levels. Such a mechanism was introduced in the Hinkley Point C (HPC) decision, where the Commission expressed concerns that the use of a contract for difference combined with

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[155] i.e., tariffs reducing over time for new providers.

[156] See Netherlands Enterprise agency website for more information: https://english.rvo.nl/information/offshore-wind-energy/hollandse-kust-zuid-wind-farm-zone-i-and-ii .

[157] 'Degressive tariffs' refers to tariffs with steadily reducing tariffs for new plants (an example of this would be a plant connected to the grid in April 2021 receiving a lower tariff than a plant connected in January 2021).
'reductions over time for existing plants' refers to tariffs with built in clauses to allow reduction over time for existing plants, typically after a period of years where tariffs are guaranteed at a certain level.
Degressive tariffs are by far the more common of the two design mechanisms but that is not to say that reductions over time for existing plants do not exist. Del Rio (2012) gives several examples: Denmark (where premia are reduced after 10 years), Latvia (where non-solar tariffs are decreased after 10 years) and Spain (where support is reduced after 20 years).

credit guarantees might allow for a significant reduction in risk once HPC was constructed, and therefore an operating cost gainsharing mechanism was built into the contract for difference mechanism where the strike price altered over time based upon operating cost. (Robins and Chakma, 2016).

2.2.4 Certificate schemes

Market-based instruments for allocating credit for renewable production exist for both CHP and renewables although they are less common than price-based support. Equally, these instruments are less studied in the literature. 25 papers study their effectiveness for investment and the majority were inconclusive. Market-based instruments are allowed under the EEAG and no preference is shown between them and FIPs.

11 papers found some positive evidence for market-based systems. A global study by Ang et al. (2017) found an 8% increase in investments per unit (1%) increase of renewable energy certificate scheme's amount produced by renewable power sources, between 2000 and 2014, compared to a 9% increase for FIT over the same period. Romano et al. (2017) found a small positive relation between investment levels and tradable certificate systems in developing countries, although, a small negative relation between investment levels was found in developed countries. Adamczyk and Graczyk (2020) and Wedzik et al. (2017) found that although green certificates in Poland initially led to a large increase in renewable capacity, high fluctuations in the value of certificates ultimately led to many investors being forced to renegotiate loan agreements, and to the price of certificates collapsing. Additionally, Adamczyk and Graczyk (2020). also found it took a long time to process applications for certificates, in some cases up to 3 years, which caused oversupply and further decreased the value of green certificates. This delay suggests that certificate schemes can have a high administrative burden. Wedzik et al. (2017) found the scheme was difficult for smaller producers to use, suggesting that complex schemes may unequally burden smaller firms. Stoltmann et al. (2019) found the CHP certificate scheme in Poland to be ineffective at incentivizing investment in CHP due to certificate prices being kept at relatively low levels.

2.2.5 Tax credits and investment tax credits

A 2010 study by Cansino et al. found that 16 Member States offered tax-based incentives for the production of green electricity. Tax credits are also common for CHP, with a 2014 Commission staff working document finding 4 Member States offered CHP providers energy tax exemptions and six offered business tax exemptions or reductions[158].

Tax credits vary in their design throughout Member States (Haas et al., 2011, Ragwitz et al., 2006) with some Member States offering a reduction in excise duties, a deduction to taxable profit, a lower VAT rate or investment tax credits which allow firms to offset some (or all) of their capital investment against future tax liabilities.

Romano et al. (2017) found investment tax credits had no significant effect on RES generation in developed countries. Rodriguez et al. (2015) found investment tax credits particularly effective in developing countries, postulating this was due to investment tax schemes often being related to a 'one off' payment. Polzin et al. (2019) suggest investment tax credits may be effective due to their importance in reducing the cost of debt.

Polzin et al. (2015) found tax credits were effective for PV technologies, but were ineffective for other technologies. Li et al. (2017) found them ineffective for wind power installations and found other measures more effective in offsetting wind's large upfront capital costs. Studies by Wall et al. (2019) and Sánchez-Braza and Pablo-Romero (2014) both found tax incentives effective for the promotion of thermal solar. Tax credits were also found to be effective for the adoption of green transport (Kester et al., 2018, Yan, 2018). Yan (2018) found that a 10% increase in tax incentive leads to a 3% increase in sales of battery electric vehicles. Mezősi et al. (2017) analyse district heating incentive schemes

[158] See Commission Staff working document, 'progress report on energy efficiency in the European Union' SWD(2013) 541 final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0541&qid=1612518578709&from=EN.

in Hungary and find that VAT reductions provide less efficient market outcomes than grants or feed-in tariffs and are also less effective from a deployment perspective. Therefore, the literature seems to suggest tax credits may be more effective when upfront capital costs are lower per unit of energy production capacity. Additionally, tax incentives will not incentivise all groups equally as some groups are tax exempt (for example local authorities, foundations and religious groups) (Gutermuth, 1998) and renewable energy providers may pay tax at different marginal rates.

Nauleau (2014) finds French home insultation tax credits have a positive impact after a latency period of two to three years, although, they find significant free-riding (40% to 85% depending on household characteristics). Olsthoorn et al (2017) find substantial free-riding in residential energy efficiency upgrade rebate schemes, finding that with a rebate of half of the purchase price, the free-rider share typically exceeds 50%.

Vollebergh (2020) investigates free-riding within the Dutch energy investment allowance (an energy efficiency scheme) and states that around 50% of users in the scheme admit they would have made energy efficiency improvements without tax rebates.

Although freeriding has been found across several different types of tax credits, given that it also appears to be an issue to other operating and investment aid schemes (see sections on grants and price-based instruments) this issue may not be directly related to the form of aid and instead, may depend on design features and industry specific conditions.

The payback period of a technology may be critical to determining if that technology should be subsidised. Vollebergh (2020) examines the payback periods of projects and concludes that investment aid is best suited to projects with somewhat long payback periods as investors are more likely to invest in technologies with short payback periods without subsidy, and thus technologies with shorter payback periods are more likely to see high levels of free-riding, equally, if a payback period is extremely long for a given technology, then that technology may be relatively expensive or deliver proportionally less benefits than its alternatives.

Barton and Schütte (2016) conduct a worldwide comparative analysis of electric vehicle adoption literature and highlight that the literature suggests sales tax waivers may be significantly more effective than income tax measures. They posit this may be due to consumers in this industry typically having a short pay-back outlook on their investments.

2.2.6 Guarantees of income

Some studies provide evidence that guarantees can allow further deployment of renewables (Gutermuth, 1998, Johnstone et al., 2010) by reducing the risk of either default on governmental power-purchase agreements or failure to disburse feed-in tariffs (Polzin et al., 2019, Mattaus and Mehling, 2020). Nevertheless, Polzin (2015) raises concerns that excessive loan guarantees can lead to the funding of low-quality projects and harm investor confidence. The cost of guarantees can be partially offset by renewable energy projects as they can pay participation fees (Mattaus and Mehling, 2020) to these instruments.

2.2.7 Grants and loans

Investment-related measures are less studied in the literature than operating aid measures (investment aid was analysed 111 times, while operating aid was analysed 274 times). Among investment aid measures, grants are studied more than lending support. Liu et al. (2019) and Polzin et al. (2015) found grants to be effective in their own right as well as when combined with other measures, particularly feed-in tariffs and tax breaks (Marques and Fuinhas, 2012, Mulder, 2008, Liu et al., 2019). This highlights that operating aid and investment aid may often be most effective when used in conjunction with each other.

Polzin et al. (2015) found grants to be effective short-term measures to alleviate finance constraints for PV and biomass. Grants were also found to be most effective in the early stages of technology development (Bergek and Jacobsson, 2013), indicating that grants may be most useful when capital and development costs are at their highest or when projects are far from being economical (Gutermuth, 1998). This is supported by Li et al.

(2017) who found grants particularly important for wind power projects as they assisted in mitigating large initial costs and improved leverage.

In 2019, the Swedish National audit office reviewed 'Klimatklivet' a local climate grant scheme and found the scheme mostly awarded aid with administrative efficiency, although, criticised the scheme for having high administrative costs compared to more general economic instruments (such as emissions trading schemes). The report suggests that this may be due to the scheme awarding aid to a variety of sectors (ranging from electric car charging stations to Biogas production) so this is not necessarily a criticism of investment aid and may be scheme specific.

The effectiveness of grants is likely to vary by Member State, as Noothout et al. (2016) found that costs of capital vary considerably throughout Europe, with the estimated weighted average cost of capital for onshore wind varying between 3.5% and 12%. Equally, grants and subsidies may be more unstable than operating aid (Polzin et al., 2015) as they temporally reduce the cost of finance for a project and depend directly on public budgets (Johnstone et al., 2010).

Investment grants can also be made for energy efficiency improvements or to facilitate conversion of non-renewable energy sources to renewable energy sources (for example changing conventional fuel production to biomass). There is concern that providing these types of investment aid grants and subsidies can lead to free-riding, whereby grants are provided to beneficiaries who would make the improvements without grants. (Grösche et al. 2013).

Broin et al. (2015) find that grants and subsides had less of an impact on the deployment of space heaters than regulatory policies such as energy labelling or minimum thermal standards for buildings and also had a longer time lag before having effect. One possible explanation for this is minimum standards force improvement whereas subsidies only provide an improvement when technology is replaced, however this criticism would hold most types of financial aid so does not appear to be a specific disadvantage of grants but rather serves to highlight that aid may be more or less effective depending on the legal framework into which financial aid is introduced.

Barton and Schütte (2017) access the effect of policy measures on electric car deployment. They group direct grants and taxation reductions together under 'fiscal measures. Although they find mixed evidence of the effectiveness of measures. Upon examination it appears that direct grants (for example those offered by the UK) were less effective than tax measures (for example those offered by the Netherlands and Norway). However, this may be due to the level of subsidy, as the effective level of subsidy for the Netherlands and Norway was effectively 75% and 55% of the base price of the electric car respectively.

Lévay et al. (2017) found lump sum subsidies for electric vehicles in France and the UK (20-27% of the purchase price with a cap) favoured smaller electric vehicles whereas tax exemptions were more favourable for larger electric vehicles. They also found that subsidy policies could lead to gaming by manufactures, for example one popular electric vehicle had a higher price in the UK (where a lump sum subsidy was available). Without government subsidy its price (including VAT) was around € 30,121, while it dropped to €23,915 after the deduction of the subsidy. In the Netherlands, France, Germany and Italy, the price was €25,520; €26,250; €26,900; and €27,150, respectively.

Polzin et al. (2015) find that preferential loans or loan guarantees may be crucial for RES deployment as they allow private actors to refinance their activities however that preferential loans are not as effective for motivating PV projects as other aid measures.

2.2.8 Price signals and market distortions

The low marginal cost of wind and PV technologies combined with operating aid subsidies can cause merit order effects resulting in substantial reductions in electricity prices (Cludius et al., 2014). In extreme circumstances, RES operating aid and the low marginal cost of PV and wind may cause prices to be negative (De Vos, 2015).

Negative electricity prices have been documented in day ahead markets in Denmark, France, Germany, the Netherlands and the United Kingdom. Deller et al. (2019) found over 720 hours of negative prices on day ahead markets in Germany and 679 hours of negative prices on day ahead markets in Denmark. Negative electricity prices have also been observed on balancing markets (Brijs et al., 2015), intraday markets (De Vos, 2015), and flexibility markets (Höckner et al., 2020). Zhong et al. (2020) find evidence that the COVID 19 pandemic may have led to an increase in the frequency of negative prices.

Low market prices, and particularly negative market prices, may harm renewable energy investment as investors may not obtain the necessary return to cover investment costs. Equally, if they led to investment decisions being subsidy-driven and not driven by market-price signals this may lock-in a subsidy dependent pathway. Hu et al. (2018) argue that this could lead to vicious cycle where price-based operating aid enlarges the gap between investment costs and market value which leads to renewable energy projects requiring more subsidies to break even. This then further disincentivises renewable energy producers from maximising market revenue, leading to a larger gap between investment costs and market revenues.

Although all forms of operating aid can potentially lead to negative or low prices, FITs are particularly likely to cause market distortions, as FITs completely shield producers from market exposure and responses to market signals whereas fixed feed-in premiums were found to create less distortions as producers are more exposed to market forces (Hu et al., 2018).

Other factors were found to influence the likelihood of negative prices: negative prices are most likely in periods with favourable supply conditions for intermittent renewable technologies (for example high irradiation levels for PV or favourable wind conditions for wind power) and low demand (Adigbli and Mahuet, 2013).

A potential remedy to these market distortions would be to provide renewable energy producers with a capacity-based payment for production over a number of years rather than a market-based payment on top of remuneration received from the electricity market (Hu et al 2018., Huntington et al., 2017).

Huntington et al. (2017) argue that a capacity-based support mechanism complemented with ex-post compensations defined for reference benchmark plants (similar to the mechanism currently implemented in Spain) could be used to completely sever the link between production and payment which would leave only market signals to dictate operating decisions. Andor and Voss (2016) provide theoretical support for capacity payments with an economic model that shows capacity payments are optimal over production-based payments as long as generation does not cause beneficial learning effects[159] and fossil fuel producers are sufficiently charged for negative externalities. Hu et al. (2018) also advocate capacity-based payments while expressing uncertainty over whether such schemes could provide sufficient security for VRE investors to de-risk their investments and limit cost of capital.

In this section we reviewed literature on the distortive effect of operating aid and investment aid and found that price-based operating aid combined with low marginal cost of PV and wind can have a distortive effect on markets, in some cases causing negative prices. Low or negative market prices may harm investor confidence and could lead to subsidy driven investment decisions which could lock in a subsidy dependant pathway.

Some forms of aid (feed in tariffs) were found to be more distortive to markets than others (feed in premiums) as feed in tariffs completely shield producers from market exposure, and responses to market signals. Therefore, policy makers need to consider the potential distortive effect of aid when designing price based operating aid instruments. Capacity based payments over time may offer a solution to these issues.

[159] Andor and Voss (2016) believe learning effects are more likely to arise from the production and installation of renewable capacity than from the generation of electricity.

2.2.9 Conclusions

This literature review has identified and analysed 172 sources with a strong European focus. 72% of these sources include at least two Member States in their analysis. The main conclusions from Section 2.2 are:

Operating and Investment aid instruments were both far more frequently found to be effective at securing investment than they were ineffective although significantly fewer instances of investment aid were observed. Feed in tariffs, Feed in premiums, Auctions, Tax Credits, Guarantees, Grants and Loans had a positive effect on levels of investment. Green Certificates, Investment Tax Credits and Direct Investment were found to have a mixed effect.

Out of the operating aid instruments studied, feed in tariffs were most frequently found to have a positive effect on investment levels however were also observed by some sources to be economically inefficient, hamper innovation and be less effective in mature markets. Feed in Premiums may offer a solution to some of these issues as they are closer to full market integration and were still found to have a positive effect on securing investment. As both of these operating aid instruments are price based, they may not be suitable for all sectors.

Tax Credits were found to be an effective measure for increasing investment in renewable energy, CHP, energy efficiency improvements and low emission mobility and thus appear to have a high degree of suitability across sectors. Tax credits were typically found to be less effective for renewable energy projects with large upfront capital costs (such as off-shore wind) and therefore may not be suitable for particularly capital-intensive sectors.

Out of the investment aid instruments studied, grants had the highest effect on investment levels. Grants may be most effective in the early stages of technology development when capital costs are at their highest or in particularly capital-intensive sectors. There was some minimal evidence of gaming with grants although this appears to be limited and within the low-emissions mobility sector.

Freeriding was found in both investment aid and operating aid schemes; although levels of freeriding varied substantiality throughout schemes, and freeriding may be more influenced scheme and sector specifics than the form of aid. Some research suggests investment aid should be awarded only to projects with long payback periods, as investors may be more likely to invest in technologies with short payback periods without subsidy.

Operating aid can have a distortive effect on energy markets and in some circumstances cause negative prices which may lead to investment decisions being subsidy driven and not market driven. A potential remedy to these market distortions would be to provide renewable energy producers with a capacity-based payment for production over a number of years.

Investment and Operating aid measures were found to be effective when used in conjunction with each other and with non-fiscal policy measures (such as minimum standards). Levels of effectiveness were also found to vary based on sector and design features. Additionally, some issues can be caused by support not being set at the correct level rather than the form of aid. Therefore, in addition to the form of aid, it is also appropriate for policy makers to consider the level of aid and the wider policy environment in which the aid sits.

2.3 Comparison of four representative renewable and cogeneration schemes with respect to investment and operating aid

2.3.1 Introduction

The objective of this section is to examine the impact the form of aid had on a representative sample of four renewable and cogeneration schemes by means of comparison. Schemes were selected from a short list provided by the Commission. A summary of the four selected schemes is provided in Table 5.

The comparison is made using publicly available sector level data, our own analysis, and interviews with relevant stakeholders.[160]

Table 5: Summary of approved sample of schemes

Sample Scheme Name, State Aid Number and Member State	Summary of the selected renewable and cogeneration schemes
Investment Aid for Solar Cells SA.40698, Sweden	***Investment aid*** scheme which supports PV deployment in Sweden. Companies, public organisations and private individuals apply for a direct grant of up to 20% of the installation costs. Aid is granted by the Swedish Energy Agency and administered locally by county administrative boards. Current iteration of scheme approved from the 1st January 2015, although investment aid for PV available since at least 2009. Scheme closed to new applicants on 7th June 2020, all installations must be completed by 30th June 2021.[161] Scheme to be replaced by a tax deduction scheme.
EEG Scheme, SA.45461, Germany SA.59842	***Operating aid*** for renewables in Germany.[162] Scheme provides price based operating aid in the form of variable market premiums and feed-in tariffs for producers with a capacity under 100KW.[163] ***Investment aid*** is also available for biogas producers in the form of a flexibility premium. Scheme overseen by the Bundesnetzagentur (Federal Network Agency). Scheme initially approved in its current iteration from the 1st January 2017 to the 31st December 2020. Prolongation of SA.45461 from 1st January 2021 to 31st December 2021(See SA.59842).
KWKG Scheme, SA.42393, Germany	***Operating aid*** for heating networks and storage. Scheme provides priced based operating aid in the form of market premiums[164] to CHP installations[165]. ***Investment Aid*** is also available for heating and cooling facilities and heating and cooling networks. Scheme overseen by the Bundesnetzagentur (Federal Network Agency). Scheme approved in its current iteration from the 1st January 2016 to the 31st December 2022.
High-energy efficiency natural gas cogeneration aid scheme, SA.43719 France	***Operating aid*** for high-efficiency cogeneration facilities powered by natural gas with a power output less than or equal to 1MW. Typically, installations in the tertiary sector. Installations of 300KW or less are eligible for a feed-in tariff, installations of above 300KW are eligible for a feed-in premium. Scheme payment mechanism via EDF. Scheme approved in its current iteration from 29th May 2016 to the 8th August 2026.

Source: UEA.

2.3.2 Comparison between operating and investment aid: PV

The investment cost of PV energy in Sweden fell rapidly between 2010 and 2013 and then continued to decline at a slower rate between 2014-2017 (see Figure 10). The cost of aid per €/MW awarded in the investment aid for PV support scheme in Sweden also decreased over the period and followed roughly the same trend (see Figure 11). Given, investment

[160] For these schemes, beneficiaries of state aid exhibited an extremely low willingness to provide information on their experience, making evaluation particularly difficult. It may potentially be valuable, as a condition of receiving state aid, that beneficiary companies be required to participate in Member State or European Commission studies of the operation of that aid, provided that the studies do not present undue time and data demands on the companies.

[161] This deadline was extended from 31 December 2020 due to the COVID-19 pandemic.

[162] Scheme covers almost all renewables production including Biogas, Biomass, Hydropower, Geothermal Energy, Onshore and Offshore Wind and Solar.

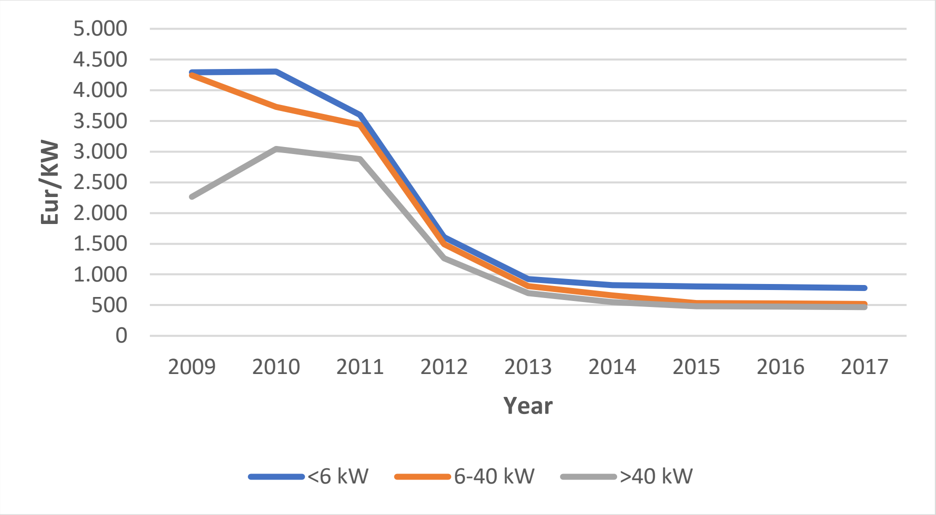
[163] Feed-in tariffs also available for larger producers but only in exceptional circumstances.

[164] Feed-in tariffs available for producers with a capacity under 100KW.

[165] CHP installations can be fired by biogas, biomass, natural gas, oil, waste or waste heat. Although existing gas-fired facilities were only eligible for support until 2019.

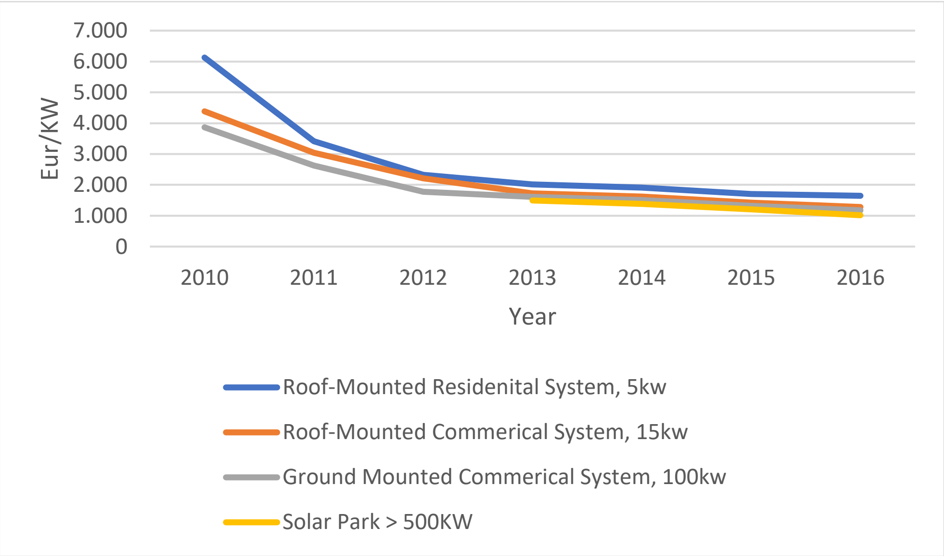
support is awarded as a direct percentage of investment costs this similarity is unsurprising. Additionally, the levels of support awarded under the scheme have also been reduced over time from 45% of eligible costs in 2011 to 20% of eligible costs in 2019.

Figure 10: Average cost of awarded investment aid [Eur/KW] for three different sizes of PV facility in Sweden



Source: Swedish National Audit Office, 2017 Converted into Eur/KW using ECB average exchange rates.

Figure 11: Average cost of solar panels [Eur/KW] for 4 different sizes of PV facility in Sweden

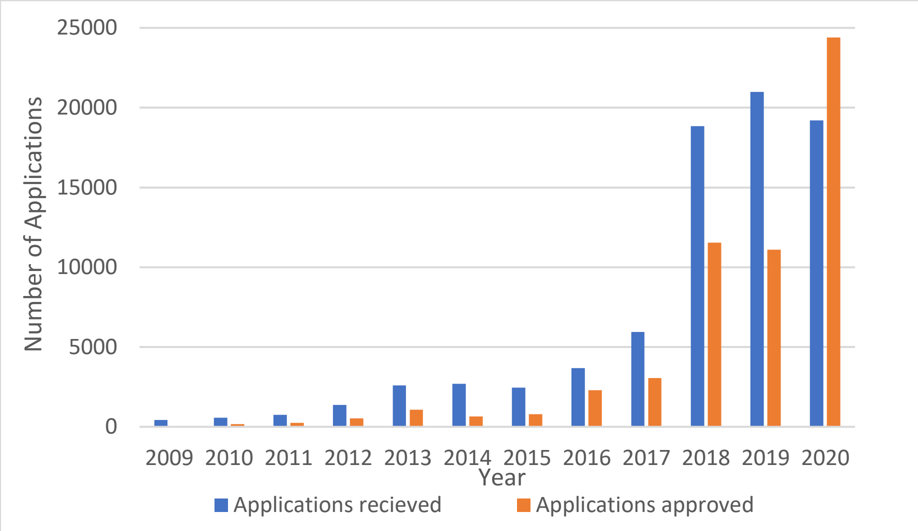


Source: Swedish National Audit Office, 2017 Converted into Eur/KW using ECB average exchange rates.

The Swedish scheme has steadily increased in popularity between 2009 and 2020 (see Figure 12) despite the levels of support decreasing[166]. This has led the budget to be significantly increased for the scheme from 58.5 Million SEK in 2011 to 1,200 Million SEK in 2020. An interviewed sector expert[167] explained that despite the scheme's popularity, uncertainty regularly remained about whether, and how much, funding would be allocated to the scheme depending on government budget. Aid and the energy law seem to be significant to a business case when seeking financial backing for projects[168].

[166] Interview with anonymous market participant, 18 March, 2021.
[167] Interview with anonymous market participant, 10 December 2020.
[168] Interview with anonymous market participant, 10 December 2020.

Figure 12: Applications received and approved for investment aid under Swedish scheme



Source: Swedish Energy Agency, 2021, Available online at: https://www.energimyndigheten.se/statistik/sol-statistik/.

PV energy investment costs in Germany fell substantially in the years up to 2012, after which costs continued to decrease but more steadily (see Figure 13). Feed-in tariff rates for PV energy in Germany roughly followed this trend although do not decrease as profoundly between 2006 and 2012 (see Figure 13 and Figure 14).

Tariffs were decreased significantly in 2012 to compensate for reductions in feed-in tariffs which did not capture the rapid decline of costs in technology, causing new capacity per year to drop from 6.6 GW in 2012 to 2.6 GW in 2013, as the scheme became less profitable for investors (see Figure 15). As mentioned by a beneficiary[169] in the interview process, their company was willing to operate in different Member States based on the different market situations in each including over the type of aid offered.

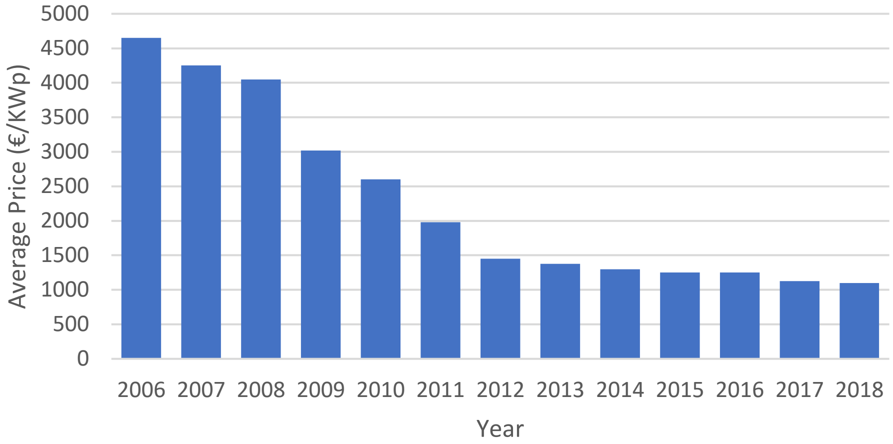
In theory, an advantage of operating aid schemes is that they mitigate the incentive for investors to wait for developing technologies, near the start of their life cycle, to become cheaper by offering them an incentive to invest immediately (Wirth, 2020). In this case high tariffs relative to technology costs led to a surge in PV investment; when tariffs were reduced relative to technology cost so did the amount of new capacity.

This experience highlights the challenge to ensure that administratively set operating aid support is set and remains at the appropriate level. This may be particularly challenging for technologies early in their product life cycle where costs are likely to reduce more rapidly as the technology becomes cheaper. In contrast, an investment aid scheme automatically takes into account reductions in the cost of technology. Additionally, gathering information to assess the falling costs of technology may increase the administrative burden for granting authorities of operating aid support schemes relative to investment aid schemes.

Since 2012, feed-in tariffs have been readjusted monthly, in response to realised installations during the previous quarter[170] (Jäger-Waldau, 2019). Aid for new ground-mounted PV systems has been auctioned by the Federal Network Agency since 2015, and the results of these tenders mirrored reductions in the cost of PV between 2015-2018 (see Figure 13 and Figure 14), highlighting the potential of competitive bidding processes to lead to cost discovery.

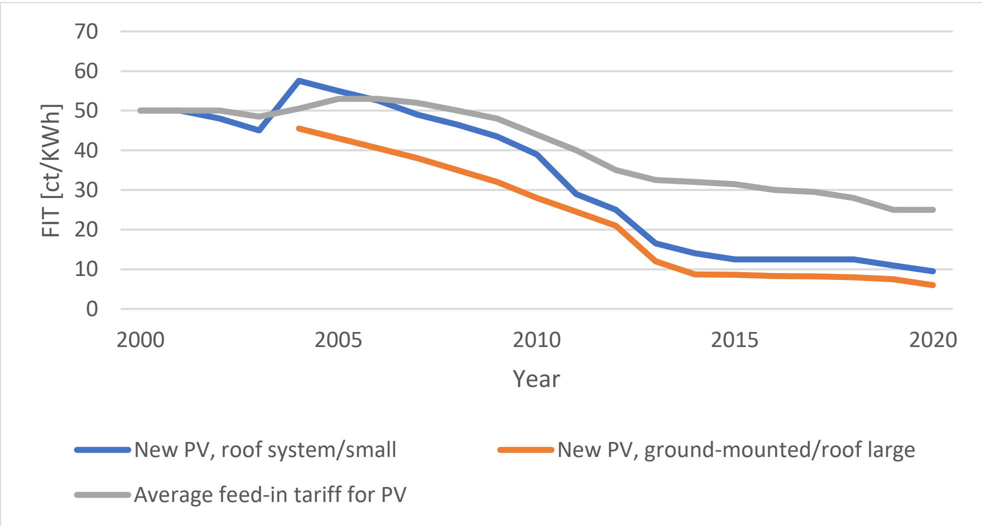
[169] Interview with anonymous market participant, 10th December 2020.
[170] Jäger-Waldau, A., PV Status Report 2019, EUR 29938 EN, Publications Office of the European Union, Luxembourg (2019).

Figure 13: Average final consumer price (net system price) for installed rooftop systems with rated nominal power from 10 - 100 kW



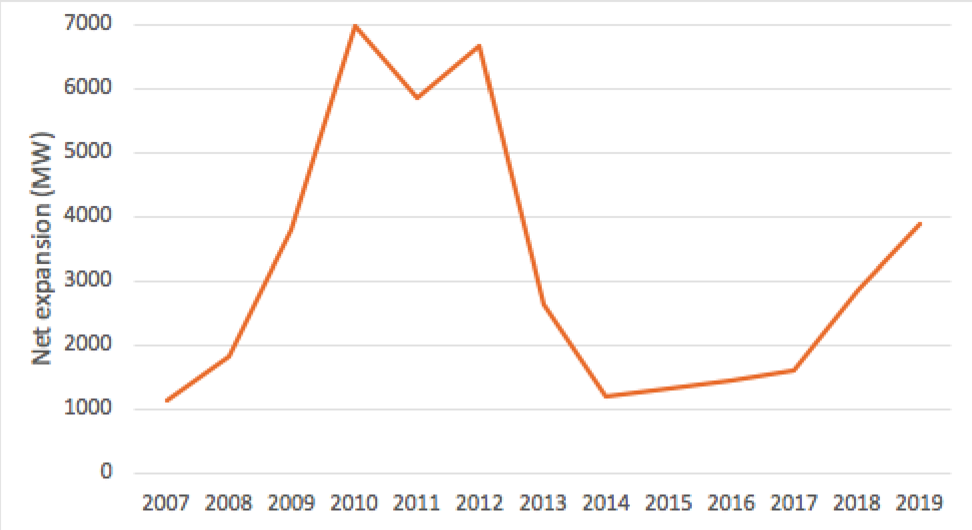
Source: UEA adaptation of Wirth, H (2020) "Recent facts about photovoltaics in Germany." Fraunhofer ISE, 92. https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html.

Figure 14: Feed-in tariff for PV power as a function of commissioning dates



Source: UEA adaptation of Wirth, H (2020) "Recent facts about photovoltaics in Germany." Fraunhofer ISE, 92. https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html.

Figure 15: PV net expansion 2007-2019



Source: Bundesnetzagentur, 2020, 'Figures, data and information concerning the EEG'. Available online at: https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/RenewableEnergy/Facts_Figures_EEG/FactsFiguresEEG_node.html.

For private individuals, the Swedish scheme is now closed to new applicants, and all installations must be built by 30 June 2021. For private individuals the scheme is being replaced with an investment tax deduction scheme, where the installation of solar panels is eligible for a personal tax reduction of 15% of the investment costs (materials and labour), limited to a maximum of SEK 50,000 (approximately €4,900) per individual per year.[171] Private Companies and public organisations can still apply to the scheme however will only receive a grant for 10% of eligible costs.

Under the tax deduction scheme, the beneficiary receives a deduction to the invoice directly from the supplier who performs the installation, the supplier then applies for a grant from the Swedish tax authority equal to the amount of the reduction. When the beneficiary completes their tax return, they disclose the amount they received and pay back any excess reduction (in circumstances where they have received more tax reduction than tax liability).

There are several possible explanations for why the investment aid scheme has been replaced. It is possible that aid was set at too low a level as a 2017 national audit report found that the investment support scheme was not in itself sufficient to reach private profitability, despite a relatively low discount rate, and that it was mainly operating aid tax exemptions for production that contributed to private profitability.[172] Furthermore, an interviewed sector expert[173] suggested that the scheme was changed as it included large uncertainties, which are detrimental for business; the new scheme is much more certain, since paying taxes ensures the reduction is directly invoiced and is not dependent on energy produced.

There is also a suggestion that the aid mechanism is a factor as a 2017 National Audit report also found users of the scheme experienced a heavy administrative burden. Only 22% of investment aid applications were made digitally and applicants had to submit both an application and then a request for payment once their application was approved.[174,175]

[171] See Swedish National Tax Authority website (2021) for further information: https://www.skatteverket.se/privat/fastigheterochbostad/gronteknik.4.676f4884175c97df4192860.html.
[172] See Swedish National Audit Office (2017) "Support to solar power", Report no. RiR 017:29.
[173] Interview with anonymous market expert, 22 February 2021.
[174] This is in addition to having to report any surplus electricity fed into the grid on their tax returns. As it is possible to claim a further operating aid tax reduction for the micro-production of electricity from renewable energy sources.
[175] Interview with anonymous market expert, 22 February 2021.

The new system can be argued to be administratively light by comparison, at least for some users, as the investment tax reduction is administered by the installation company. All the individual has to do is complete an additional section on their tax return, the majority of which are filed online.[176]

Furthermore, under the tax deduction scheme, the beneficiary receives the aid upfront rather than having to wait for their application to be processed. Evidence from the Swedish Energy agency (2018) [177] found that investment aid scheme applicants had, in some cases, had to wait up to 700 days for a decision on their applications and that the applications were overly complicated. This feedback is supported by qualitative feedback, as one of the companies contacted for interview (who by the end of 2018 had over 50 PV systems in operation) did not apply for investment support as they felt that it too time consuming a procedure.[178]

Additionally, under the investment aid scheme, the number of beneficiaries which could receive aid was limited by a budget. There was no guarantee that applicants would receive aid. In some cases, this led to applicants applying for 'a root and square' reduction. The root and square reduction is a tax deduction for a wide array of home improvements and repairs which has been available for to private individuals since 2009. It functions similarly to the tax deduction for green technology scheme, however, offers support at much lower rate, an equivalent of 9% of total costs.[179]

Although the root and square reduction and the investment aid grant could not be used in conjunction with each other, applicants were allowed to apply for both and then pay back the root and square reduction if they were successful in securing an investment aid grant.[180] This no doubt led to an unnecessary administrative burden for the Swedish authorities, as in these circumstances aid would have to be administered to beneficiaries twice.

Furthermore, aid under the investment aid scheme was granted by 21 different county administrative boards. A 2018 report by the Swedish Energy Agency[181] found that differences in how they handle processing and smaller boards not being able to devote staff full time to process applications led to regional disparities in an applicant's chances of receiving aid. As the tax scheme is administered nationally it is less likely to lead to regional disparities. By contrast, the administrative burden of Germany's EEG on PV beneficiaries has historically been praised. A 2012 study by Garbe et al[182], found the legal-administrative processes related to PV in Germany the lowest in Europe. Equally, a study by Seel et al (2014) found the German FIT a relatively straightforward value proposition, which may have helped in the diffusion of PV compared to countries with more complex support systems[183].

Lastly, a sector expert[184] pointed out that when a Member State establishes a scheme (or re-designs it, in the case of amendments to a previous scheme), one large issue is how

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[176] See Swedish National Tax Office (2019) 'Record numbers declared digitally' https://www.skatteverket.se/omoss/press/pressmeddelanden/2019/2019/rekordmangadeklareraded-igitalt.5.8bcb26d16a5646a1489ab.html.
[177] See 'Förenklad administration av solcellsstödet' (2018) available through Enegimyndighetens website: https://energimyndigheten.a-w2m.se/Home.mvc?resourceId=104688.
[178] As this interviewee installed aid without investment aid it may be that the scheme was not required although it is not clear if the interviewee used the 'root and square' deduction discussed in the paragraph below.
[179] This scheme offers a 30% reduction to installation labour costs, this was estimated to be a 9% reduction to total costs of installation costs in a report by the Swedish Energy Agency. See https://www.skatteverket.se/privat/fastigheterochbostad/rotochrutarbete/gerarbetetratttillrotavdrag.106.5c1163881590be297b5899d.htm.
[180] See 'Förenklad administration av solcellsstödet' (2018) available through Enegimyndighetens website: https://energimyndigheten.a-w2m.se/Home.mvc?resourceId=104688.
[181] See Swedish Energy Agency (2018), "Förenklad administration av solcellsstödet".
[182] Garbe, K., M. Latour, and P. M. Sonvilla. "Reduction of Bureaucratic Barriers for successful PV deployment in Europe." *Project PV Legal* (2012).
[183] In particular Seel et al compare the FIT system in Germany to the system in the united states which mostly consists of tax credits, local incentives and net-metering policies. For more information, see Seel, J., Barbose, G.L. and Wiser, R.H., 2014. "An analysis of residential PV system price differences between the United States and Germany." Energy Policy, 69, pp.216-226.
[184] Interview with anonymous market expert, 22 February 2021.

the scheme is communicated to the market. The Swedish government formally announced the end of the previous investment aid scheme for private households about a month prior to its removal though there were prior public discussions that suggested the possibility of the scheme ending; some applicants allegedly fell in the gap of the two schemes and could not benefit from either the previous scheme (since it ended) or the new scheme (as they were no longer eligible). Communication methods and transition times were considered important topics for market participants.

2.3.3 Comparison of operating aid and investment aid within a scheme: Biogas under the EEG

The EEG scheme is largely made up of operating aid support for renewable energy through market feed-in premiums. In addition to the feed-in premium, biogas and biomethane CHP producers may also claim a flexibility premium.

The flexibility premium is designed to allow biogas and biomethane CHP producers to expand capacity in order to ensure a higher proportion of flexible energy in the grid in order to compensate for an energy mix more heavily relevant on intermittent renewables such as wind and PV. In order for additional capacity to be flexible it cannot be used continuously as it needs to feed into the grid in times of high demand. As investment costs are less likely to be recouped if a plant is not allowed to operate at full capacity continuously for new plants the flexibility premium provides an additional 40€/KW/year subsidy to compensate for periods where the additional capacity in a plant is inactive. The funding is limited to cover the average additional costs for the provision of flexible capacity of up to 50% of installed power over the lifetime of the facility.[185] For existing plants, the level of flexibility premium payment depends on the quotient of rated and installed capacity (PQ quotient). The more a plant increases its installed capacity, whilst holding rated capacity constant, the greater the subsidies it will receive. In both circumstances the flexibility premium is administratively set, whereas market premia are competitively set for most facilities over 100KW.

The flexibility premium is an interesting example of aid, relating solely to recuperating investment costs, and therefore very close to investment aid; however, as it is offered over the lifetime of a plant and can be claimed by both new and existing plants it has characteristics of operating aid.

Purkas et al. (2018)[186] assess the effectiveness of the flexibility premium and find that in general it is capable of bringing about investment in flexibility. They also highlight that for new biogas plants the limitation of funding to 50% of power rating should ensure flexible operation however existing plants receiving the flexibility premium are not guaranteed to operate in a flexible manner by receipt of the premium although it is likely given that in order to receive the premium they have to have created the necessary technical conditions to generate electricity in a flexible manner (i.e., rated capacity has to be significantly lower than installed capacity).

Scheftelowitzz et al. (2018)[187] also find that the flexibility premium is becoming a successful instrument as the number of power plants participating in the scheme is increasing rapidly, with 1657 biogas and 336 biomethane fired plants receiving the flexibility premium in 2015, with an installed capacity of 1026MW and 336 MW respectively.

Laurer et al. (2017)[188] analyse the costs and economic feasibility of flexibility for existing plants and find that flexibilization of an existing plant with a rated power of 800KW to a PQ value of 1.5 costs €33,000 per year and raising flexibility to 2.1 costs €99,000-

[185] See Commission Decision SA.45461.
[186] See 'Purkus, A. et al. 2018. Contributions of flexible power generation from biomass to a secure and cost-effective electricity supply—a review of potentials, incentives and obstacles in Germany. *Energy, Sustainability and Society*, *8*(1), pp.1-21.
[187] Ibid.
[188] See Lauer M, Dotzauer M, Hennig C, Lehmann M, Nebel E, Postel J, Szarka N, Thrän D (2017) Flexible power generation scenarios for biogas plants operated in Germany: impacts on economic viability and GHG emissions. Int J Energy Res 41(1):63–80.

€118,000 per year. This highlights that the costs of upgrading a facility are not linear. Scheftelowitzz et al (2018)[189] found that the average PQ of biogas firms participating in the scheme in 2015 was 2 and biomethane plants was 3.9. This suggests that firms that do use the scheme are opting to make substantial investments in improving flexibility.

As solid-state biomass is not eligible for the flexibility premium, additional investments in biomass are entirely dependent on investments offering a reasonable rate of return. Flexibility may require a higher level of investment for solid state biomass than for biogas plants as solid-state biomass plants do not have efficient storage facilities. Thus, in order to participate in flexibility markets, plants often need to expand capacity (Purkas et al 2018).[190]

A 2013 questionnaire by Lehmann[191] found 29.5% of solid biomass plant operators were participating in balancing markets and a further 10.5% were preparing to, suggesting that there is still market incentive for some of these providers to enter flexibility markets without investment support.

This survey also found that 12% of respondents did not participate in balancing markets due to unclear or complex procedure, suggesting that there may also be non-financial barriers for the participation in balancing markets. The resolution of which could improve participation in balancing markets and thus decrease the need for investment support.

The actual payments for the flexibility premium are relatively low in comparison to the total payments made to biomass under the EEG; however, they are steadily increasing as new flexible biogas installations are entering into operation (see Table 6). This, combined with the evidence from the literature, suggests the flexibility premium is a relatively effective measure at securing investment in expansion of biogas facilities; however, participation in flexibility markets may be improved if non-financial barriers (such as unclear or complex procedure) are reviewed.

Table 6: Biomass: Total Production, Total EEG payment, Biogas: Total flexibility payments

Year	Biomass Total Production (GWh)	Biomass EEG Payments (€ mil)	Biogas Flexibility Premium Payments (€ mil)
2014	25,495	3,734	-
2015	29,475	4,426	42.5
2016	31,197	4,829	56.5
2017	32,382	4,905	80.8
2018	32,809	4,696	114.9
2019	33,292	5,030	158.7

Source: Bundesnetzagentur (2020) 'Figures, data and information concerning the EEG'. Available online at: *https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/RenewableEnergy/Facts_Figures_EEG/FactsFiguresEEG_node.html.*

2.3.4 Combined heat and power under the KWKG

The KWKG provides both operating aid in the form of a market premium for CHP plants and investment aid in the form of a direct investment grant for district heating and cooling facilities. Investment aid is provided in addition to operating aid as heating and cooling facilities allow for CHP systems to be operated with a higher degree of flexibility and thus

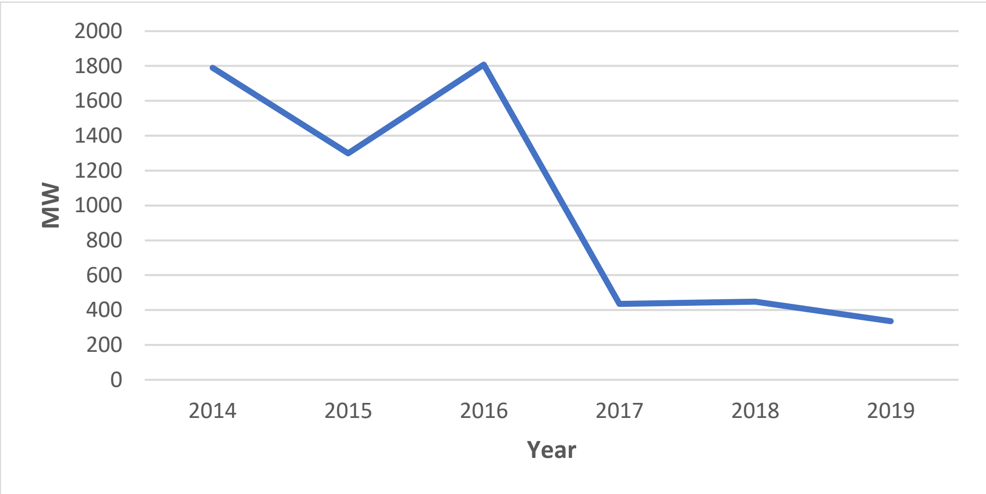
[189] See Scheftelowitz, M., Becker, R. and Thrän, D., 2018. Improved power provision from biomass: A retrospective on the impacts of German energy policy. *Biomass and Bioenergy*, *111*, pp.1-12.
[190] See Purkus, A. et al. 2018. Contributions of flexible power generation from biomass to a secure and cost-effective electricity supply—a review of potentials, incentives and obstacles in Germany. *Energy, Sustainability and Society*, *8*(1), pp.1-21.
[191] See Lehmann S (2014) Auswertung "Fragebogen bezüglich technischer Anforderungen an Biomasse(heiz)kraftwerke für die Beteiligung am Regelenergiemarkt". In: Nelles M (ed) Tagungsband "DBFZ-Jahrestagung 1.-2. Oktober 2014". Deutsches Biomasseforschungszentrum (DBFZ), Leipzig, pp 88–96.

compensate for the volatile electricity generation of renewable energies.[192] Investment aid is also available for heating and cooling networks. Differences in aid available for heating and electricity were described by an interviewed sector expert[193] as one of the elements which hindered the effectiveness of the scheme as calculating these are very complicated. For instance, the scheme distinguishes between electricity and the heat produced, since the measure aims at supporting mainly electricity generation and the same aid for heating production does not exist.

Investment aid and operating aid under the KWKG appear to serve different objectives. The investment aid for district heating and cooling facilities/networks helps improve system flexibility whereas operating aid for CHP plants allows a CHP plant to cover operating costs. As mentioned in beneficiary interview data[194], operating aid is generally higher risk for beneficiaries as plants must first be built and in operation before aid can be received. For plants already in operation, operating aid had contributed significantly to increased electricity and heating production. Investment aid was additionally considered very important to the realisation of new plants, without which new projects would not have economic feasibility. Finally, without operating aid this particular beneficiary would not have commissioned CHP plants abroad.

Newly installed CHP capacity fell rapidly from 2016 to 2017 (see Figure 16) which coincides with firms over 100KW were only eligible for aid in the form of a market premium. However, this also coincides with when aid awarded to new installations with over 1MW of capacity had to be awarded through a competitively set process and when coal installations were no longer eligible for support, therefore this may have been caused by a variety of different factors.

Figure 16: Total CHP Capacity Approved [MW] under the KWKG by BAFA by year of commissioning



Source: BAFA (2020) Statistics on "Authorized CHP systems 2009 to 2019". Available online at: https://www.bafa.de/SharedDocs/Downloads/DE/Energie/kwk_statistik_zulassungen_2009_2019.html.

5 out of 6 auctions for CHP held between 2017 and 2020 awarded total aid under the amount of aid advertised for the auction, suggesting the shift to competitively awarded market premiums may have been a factor in the decline of new capacity awarded. Furthermore, in some cases installations have been curtailed pursuant to German Curtailing Laws and the CHP Act as explained by an interviewed beneficiary.[195] It was highlighted that the CHP Act holds many uncertainties long-term, and any legal changes made significantly affect feasibility of investments and continuation of ongoing plant construction.

[192] See BAFA website https://www.bafa.de/DE/Energie/Energieeffizienz/Kraft_Waerme_Kopplung/Waerme_Kaeltespeicher/waerme_kaeltespeicher_node.html.
[193] Interview with anonymous market expert, 24 February 2021.
[194] Interview with anonymous market participant, 11 February 2021.
[195] Interview with anonymous market participant, 15 February 2021.

Lack of planning security was seen as a main reason for decreased use of funding mechanisms. It was emphasised that the abrupt ending of the initial KWKG scheme in 2026 did not provide an adequate timeframe for project planning and commissioning duration within the last years of the scheme. Therefore, projects which are underway would be completed, however, this beneficiary thought new project uptake unlikely due to the remaining time available when considering the planned 2026 scheme end.

Beneficiary interview data[196] identified that administrative burden was high due to difficulties interpreting the relevant provisions and guidance when applying for aid. For this particular beneficiary the additional work added costs and complexity which required involvement of external experts and lawyers and a process time of weeks for a full-time team.

These findings are consistent with another beneficiary [197] who highlighted CHP planning, construction of new plants, preliminary subsidy approval and application for the aid as the main areas of administrative burden relating to aid under the KWKG scheme. When planning CHP construction, consideration must be given to specific plant measures needed in order to provide certainty of receiving aid; as a result, this beneficiary applies for preliminary approval, adding to administrative burdens. Once constructed, new plants must undergo examination by external experts, secure specific permits and Commission approval, adding to administrative burden. Following preliminary approval and plant commissioning the aid application is finally submitted; the entire process is accompanied administratively and takes several years.

An interviewed sector expert[198] also reinforced these findings by explaining that administrative burden represents an element that hinders potential candidates from applying for the aid. This is especially true for heating, since a choice exists between a classic plant and a cogeneration plant. A large amount of administration is required for a cogeneration plant to be efficient and this may be daunting for a potential beneficiary. As a result, an individual might prefer to run a classic generation plant instead. Cogeneration reporting tasks are particularly difficult for micro-producers who are not familiar with such technicalities. It is therefore likely that investment aid would be more accessible for beneficiaries.

A sector expert[199] also highlighted that operating aid entails a large amount of administrative burden, as reports are required to assess allocation of aid based on energy generation. Difficulty arises when reporting the amount of energy produced, but also when this amount has been generated and all the hours during which energy has been produced under that condition must be aggregated. Therefore, investment aid was described as preferable from an administrative burden viewpoint.

A report[200] for the German Ministry and Economic affairs and Energy (BMWi) evaluates current CHP operating aid mechanisms (market premiums and tenders) with alternative aid mechanisms in order to assess if switching aid mechanisms would lead to a more preferable outcome. Notably investment aid and investment tax credits are included as alternative mechanisms and thus the report provides analysis on the merits of operating aid and investment aid schemes.

The report finds price-based operating aid measures are more effective from a production perspective as firms which receive investment support are entirely reliant on the price of

[196] Interview with anonymous market participant, 15 February 2021.
[197] Interview with anonymous market participant, 11 February 2021.
[198] Interview with anonymous market expert, 24 February 2021.
[199] Interview with anonymous market expert, 24 February 2021.
[200] See Fraunhofer IFAM, Öko-Institut e.V., BHKW-Consult, Stiftung Umweltenergierecht and Prognos AG. 2019. 'Evaluation of combined heat and power – analysis of the development of combined heat and power in an energy system with a high share of renewable energy' available at https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/evaluierung-der-kraft-waerme-kopplung.html.

electricity to make their production profitable and thus are less likely to produce when electricity prices are low.

The report also suggests investment support schemes may be a more electricity market-compatible investment (as investment support can be tailored to specific improvements such as investments to help existing plants enter flexibility markets). However, this benefit is significantly outweighed by a stronger positive effect on production offered by operating aid measures. The report recommends keeping CHP support in its current format.

Investment aid support for heating and cooling networks and storage facilities remained at a constant level throughout the support period although the total amount of aid available was increased in the 2016 Combined Heat and Power Act.[201]

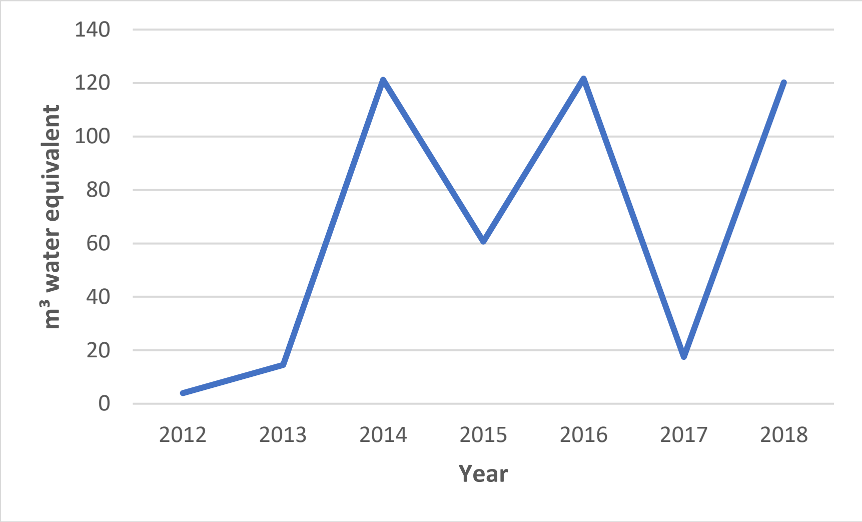
The scheme for micro cogeneration plants was identified as not useful by an interviewed sector expert.[202] They explained that, even with the aid, plants are not cost efficient (although they are more energy-effective than normal plants). For example, very small cogeneration plants (1 to 5Kw) are relatively common in Germany. However, energy savings and aid received are modest and does not allow investment pay off. They remain common as it may be an interest for plant owners, but profit is not attained. In addition, it is uncertain that small cogeneration plants are useful for the energy market, as they run regardless of market needs. It is also likely that these micro plants are replacing renewables and that they are not energy efficient. However, the negative impact is slightly reduced when there is a network of small plants.

Beneficiary interview data[203] highlighted that compensation from the Federal Network Agency (Bundesnetzagentur) can be secured through transitioning to natural gas, with subsequent CO_2 reductions of 0.6 tonnes per year from one example provided. CO_2 emission reductions can be gained through efficiency and utilisation rate of CHP plants; older plants have roughly 33% efficiency compared to 55% for newer plants which, it is assumed, would further incentivise applications for investment aid support.

Total approved storage capacity awarded to heating and cooling facilities fluctuated heavily throughout the period between 2012 and 2018 (see Figure 17). Approved new capacity of heating and cooling networks declined steadily between 2012 and 2018 (see Figure 18). There is no obvious relationship between these changes and changes in aid awarded through operating aid and investment aid. Furthermore, investment aid may be a more suitable mechanism of providing aid than price based operating aid for these networks and facilities as they do not directly produce power and thus it is more difficult to link their value to a price of production.

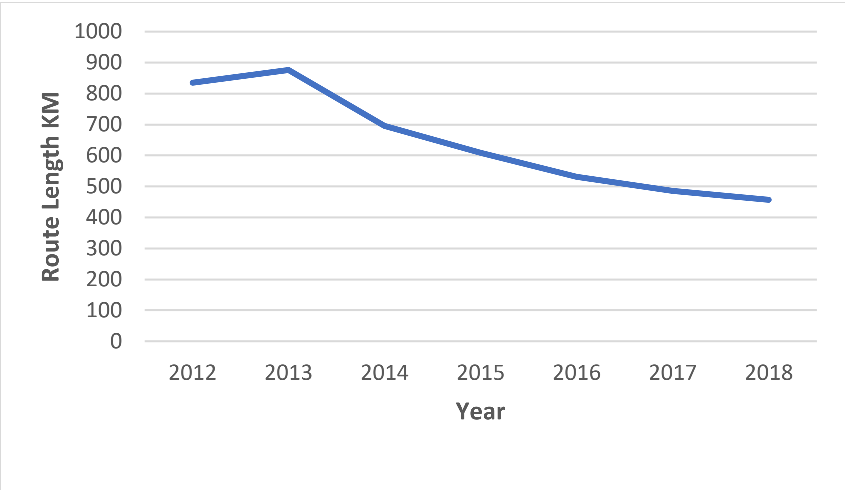
[201] See table 4.3 of https://ec.europa.eu/energy/sites/ener/files/documents/de_-_tr_into_eng_-_5th_progress_report_red_for_2017_and_2018.pdf for investment grant rates.
[202] Interview with anonymous market expert, 24 February 2021.
[203] Interview with anonymous market participant, 15 February 2021.

Figure 17: Approved Storage Volume, Heating and Cooling Facilities [m³ water equivalent] Awarded aid by BAFA under the KWKG 2012-2018



Source: BAFA (2020) Statistics on "Authorized CHP systems 2009 to 2019". Available online at: https://www.bafa.de/SharedDocs/Downloads/DE/Energie/kwk_statistik_zulassungen_2009_2019.html.

Figure 18: Approved New Capacity, Heating and Cooling Networks [Route Length KM] Awarded by BAFA under the KWKG 2012-2018



Source: BAFA (2020) Statics: Approved heating networks 2009 to 2019. Available online at: https://www.bafa.de/SharedDocs/Downloads/DE/Energie/kwk_waerme_kaeltenetze_statistik_zulassungen_2009_2019.pdf?__blob=publicationFile&v=14.

2.3.5 High-energy efficiency natural gas cogeneration aid scheme

The French scheme for high efficiency cogeneration facilities powered by natural gas provides operating aid support through a feed-in premium for combined CHP plants up to 1 MW and a feed-in tariff for plants up to 300 KW. This aid is awarded for a duration of 15 years, which is considered the normal lifespan of a natural gas cogeneration plant. The scheme aims to encourage integrated electricity production from CHP plants, focusing on plants which are smaller in size.

The administrative burden of obtaining aid was considered from the outset of this scheme. Previous similar schemes had administrative processes involving a Contrat Ouvrant Droit à l'Obligation d'Achat (CODOA); a certificate allowing plant owners to sign a Power Purchase Agreement alongside EDF with a 15-year fixed feed-in tariff with a right to the obligation of purchase. However, the introduction of this scheme, in 2016, saw a change from using the CODOA to a Certificate of Honour, which required less detail and has a quicker verification process, in order to reduce the administrative burden of securing aid.

As indicated in France's multi-year energy plan (known by its French acronym PPE), investment into CHP is set to decrease in alignment with green energy targets. In 2018, the PPE trajectory for energy policy specified that the state will end support systems for new natural gas cogeneration facilities. Additionally, promotion of heat recovery from biomass is to be prioritised over high efficiency cogeneration. Payments for cogeneration support are planned to decrease over the next 7 years with the majority of the remaining payments awarded to timebound contracts, many of which will end within this timeframe.

CHP infrastructure is planned to change in France as operating support given under the state aid scheme has encouraged more small- and medium-sized CHPs plants. The PPE trajectory looks to transition CHP installations to incorporate biomethane use alongside natural gas. Additionally, the PPE has specified that electricity production from solid biomass will not receive financial support from the state which is comparable to the specifics of the flexibility premium within the German EEG scheme discussed in section 2.3.3. Given this trajectory, it is important to consider that gas cogeneration networks may be easily converted for biogas use and it may not require considerable work and investment to adapt infrastructure when implementing these changes. The gas cogeneration sector, now segmented into several power classes, remains subject to strong uncertainties with no clear future in the medium term despite the presence of state aid operating support until 2026.

Data collection has focused on data available through the European commission, 'state aid transparency public search' function which requires granting authorities to provide information on individual aid awards above €500,000 after July 2016[204]. Records show 22 instances of aid awarded under the high-energy efficiency natural gas cogeneration aid scheme to 10 beneficiaries between 2018 and 2020. This is significantly fewer entries than the EEG Scheme with 846 instances of aid awarded to approximately 550 beneficiaries[205] between 2017 and 2018 or the KWKG Scheme with 7932 instances of aid awarded to approximately 3081 beneficiaries between 2016 and 2020.

Given that the high efficiency cogeneration scheme is aimed towards cogeneration facilities of 1MW and under, it is unsurprising that the 'state aid transparency public search' displays significantly less beneficiaries as the many beneficiaries may be under the reporting threshold of €500,000. Nevertheless, Table 7 suggests that aid awarded under the scheme has expanded between 2018 and 2019 and then decreased in 2020.

Table 7: Total Payments (EUR) of over €500,000 awarded under the high-energy efficiency natural gas cogeneration aid scheme 2018-2019

Year	Payments (EUR)
2018	6,786,847
2019	13,780,342
2020	5,461,515

Source UEA, derived from EC state aid transparency platform.

2.3.6 Conclusions

The four schemes reveal a vast diversity in the awarding of operating and investment aid, both in scope and effectiveness. The case studies demonstrate that both operating aid and investment aid can be effective in increasing energy production capacity. The form of aid appears to influence key factors such as level of administrative burden, legal clarity and overall ease to secure support, however these also vary from scheme to scheme; therefore, drawing direct conclusions is difficult. Nevertheless, some interesting observations can be drawn. The summary conclusions from Section 2.3 are:

[204] See https://webgate.ec.europa.eu/competition/transparency/public?lang=en.
[205] Number of beneficiaries estimated by downloading entries under SA.45461 and SA.42393 and then removing duplicate names of beneficiaries.

Both the Swedish investment aid scheme for PV and the EEG were effective in increasing PV capacity, whilst aid levels and the costs of technology fell rapidly throughout the period. Given the rapid decline in costs for PV, at times, the EEG struggled to keep administratively set feed-in tariffs in line with the investment costs of technology. Competitive bidding processes provide a solution to this problem and also lead to more effective cost discovery. Although the Swedish investment scheme was an effective measure in securing investment in PV it was administratively cumbersome, time consuming for both beneficiaries and administrators and limited by budget constraints. Its replacement, a tax deduction scheme may provide remedies to these issues.

The German flexibility premium for biogas is a relatively effective measure at securing investment in expansion of biogas facilities; however, participation in flexibility markets may be improved if non-financial barriers (such as unclear or complex procedure) are reviewed.

Total amount of approved CHP capacity under the KWKG scheme slowed over the period. A shift away from administratively set feed in tariffs to competitively set market-based premiums may have influenced this as beneficiaries reported the new system was administratively cumbersome and harder to understand.

Limited data made drawing conclusions on the high-energy efficiency natural gas cogeneration scheme difficult although data available through the state aid transparency search scheme suggests that aid awarded expanded between 2018 and 2019 and then decreased in 2020. The scheme may also be less administratively cumbersome than its predecessor.

2.4 Comparison of three hypothetical support schemes impacts on industrial decarbonisation for steel, cement and ammonia

2.4.1 Introduction

As industrial carbonisation becomes a greater focus of policymakers and state aid, it is worth considering different forms of operating and investment aid that could be implemented to further the transition, with dual goals of ensuring effectiveness and the efficient use of funds. Hypothetical support schemes have been devised for:

- schemes based on fixed aid intensities (calculated on extra environmental costs);
- schemes based on a carbon contract for differences; and
- schemes based on a funding gap approach.

These hypotheticals are applied to steel, cement and fertilisers. Fertilisers in this instance focus on ammonia as the main activity of interest due to its preponderant role in fertilisers, its specific technologies that are susceptible to analysis and better information available about ammonia. The hypotheticals are discussed in the following subsections. These are followed by summary data and then analysis. CO_2 reduction from the different approaches can be quite high, approximating 100% of process CO_2 reduction to the extent that carbon capture storage (CCS) is included and successful.

2.4.2 Fixed aid intensity

The fixed intensity regime begins by calculating the investment differential between the commercially "normal" regime, absent the environmental goals, and the investment required for meeting the environmental goals. Under normal circumstances, a maximum of 40% of this difference is then deemed eligible for aid under current EU guidelines. Bonuses can be provided cumulatively for SMEs, assisted regions and eco-innovation. Higher aid intensities can amount to between 10% and 20% for medium and small enterprises respectively, 15% in assisted regions, and 10% for eco-innovation. Aid granted based on a competitive bidding process can reach 100% of the difference.

As a formula, this may be written as:

$$FI * DEI = FI\ (DDI - DBI) \qquad (1)$$

where

- FI is Fixed Intensity, i.e. the maximum percentage of the differential that can be covered (30% for energy efficiency; 40% for environmental protection; 45% for renewables);
- DEI is discounted eligible investment;
- DDI is discounted desired investment (for achieving the goal of the state aid);
- DBI is discounted base investment (that would occur absent the goal).

The key element of fixed aid intensity schemes is the level at which the aid intensity is set. The aid intensity approach has traditionally been used to incentivise construction of renewable energy production facilities that potentially have much lower variable costs of production than traditional energy production technologies. Therefore, whilst the 45% level may have been effective for the promotion of PV, wind and water this approach has less initial promise for the industrial decarbonisation of steel, cement and fertilisers as expert analyses suggest these are expected to have variable costs that are equal or higher than their respective traditional technologies.

Even in the extreme case in which an enterprise cumulates all forms of bonus, the aid would still not cover the entire differential.

If such a scheme were used, it would need to increase the level of support so that, from the perspective of an investor, the decarbonising technology would make more financial sense than the traditional technology. This would effectively require total amounts of aid level (including any bonuses) of 100% of the differential, in the case where operating costs do not fall. Even if the level is augmented to 75-80%, which would theoretically permit for 100% of the differential in the instance with 2 cumulative bonuses (excluding the small or medium sized enterprise bonus), the general situation for enterprises not in assisted areas or with eco-innovation, would be under 100%.

To illustrate these points further, when assessing the necessary level of support needed to incentivise a new technology over an old one, relevant factors include not only the change in costs (assumed to be an increase) in investment for the new low carbon technology compared to the prior technology as well as the difference in operating costs between the prior technology and the new technology. We can compare cases (i) in which operating costs are lower for the new than the prior technology, (ii) in which operating costs for the two technologies are the same and (iii) in which operating costs for the new technology are higher than for the prior technology. In the first case, with lower operating costs for the new technology than the prior one, levels of support for investment under 100% of the differential can still incentivise investments, though the precise level necessary depends on the extent to which operating costs are lower for the new technology and may permit higher earnings. In the second case, with no change in operating costs, a level of support below 100% of the differential, such as the existing 40%, will not be sufficient to incentivise on its own the new investment because the more profitable option would continue to be investing in the prior technology, since the private investment level would be lower than for the new technology, and earnings would be the same. In the third case, when operating costs are higher for the new technology than the prior technology, even investment aid of 100% of the differential would not be sufficient to incentivise installation of the new technology, absent further support to cover the increased operating expenses.

For discounting, a 5% financial discount rate in real terms may be used as indicative benchmark but can be modified in a fair and transparent manner.

2.4.3 Carbon Contract for Difference (CCfD)

The carbon contract for difference approach involves setting a contract price for carbon. This price is then compared to an external benchmark for the current value of carbon, which changes over time. The contract for difference involves setting a contract price for carbon with the investor company so that when the external benchmark is below the contract price, the investor is made whole for the difference between the contract price and the external benchmark with a payment from the contract issuer. If the external benchmark is above the contract price, it can be foreseen that the contract receiver returns the difference (between external benchmark and contract price) to the contract issuer (bidirectional contract). For the case study, the model of a bidirectional contract for difference is used. This provides the state with a more symmetric risk and reduces chances of windfall private sector gain.

The effect of the carbon contract for difference is to provide a stable price for the carbon reductions from installing a new or breakthrough technology, whether for reducing CO_2 directly or for carbon capture and storage (CCS). The focus of the CCfD directly on CO_2 reduction makes the financing mechanism particularly clearly focused, as would be ideal for industrial decarbonisation, which would include many different technologies with cost features that may evolve and be difficult to analyse in the beginning (though investors would necessarily have to make such an analysis, suggesting such an analysis is possible).

It has been argued that the debt-equity ratio can alter in such a system, because the CCfD creates a stable net revenue stream that can, in turn, permit higher debt levels. The higher debt level, from private sources, is in turn expected to have a lower cost per Euro invested than equity. Having said that, the lower risk level for equity (even if the ratio of equity to debt is higher) can reduce the expected return on equity, assuming the equity risk has fallen due to the stable revenue.

The formulas for CCfD payments are:

$$\textit{Investor ETS savings compared to normal process}_t = ETS_t * (Q_b - Q_i) \qquad (2)$$

$$\textit{CCfD payment to investor}_t = (P\text{-}ETS_t) * (Q_b - Q_i) \qquad (3)$$

Note: if $ETS_t>P$, then the investor project faces a "high" ETS price (thus receiving high savings or earning from sale of certificates) and returns "surplus" to the CCfD contract granting body; if $P>ETS_t$, the project faces a "low" ETS price (thus receiving low savings or low income from sale of certificates) but then receives back funds from the CCfD granting body

$$\textit{Total carbon related payment/income for investor} =$$

$$ETS_t \textit{ payment} + CCfD_t \textit{ Payment} = P\,(Q_b - Q_i) \qquad (4)$$

Note: Variability of ETS prices is thus eliminated from investor calculations, allowing a known carbon price for investment calculations

where

- Q_b: Benchmark output of carbon (tons) per unit of output[206];
- Q_i: Innovative project output of carbon (tons) per unit of output;
- P_d: Project CCfD contract price;
- ETS_t: Carbon market price (ETS spot at time t).

Due to their complexity and length, the key elements of the CCfD hypothetical scheme selected are indicated in Annex 8 in a table with **bold** text indicating the selected option, while mentioning other options and a reason for selecting the chosen one. Two particular options are selected for separate analysis, **option 1** and **option 2**, in which competitive bidding processes for CCfD are either multi-industry or single industry, respectively. These two options are separated out because of their fundamental importance for determining how roll out would occur. Due to the rank ordering of costs of break even for new technologies across industries and technologies, there can be a possibility of high focus on one industry in a multi-industry approach, potentially at an oligopolistic level or at the level of the next most expensive technology in the rank order. To the extent that a range of costs between industries are close or ranges overlap, this possibility is reduced substantially.

One feature of a CCfD scheme is that an entity (that can be presumed to be government backed) is guaranteeing a payment to the investor when the ETS price is less than the project CCfD contract price. This creates a risk for the government as the financial backer

[206] The carbon output considered for Q_b and Q_i are the direct emissions, excluding emissions linked to fuel production.

of the guarantor entity. Ultimately, to counteract these risks, government may have financial incentives to raise ETS prices to avoid the financial risk or even to turn the CCfD into a revenue generating entity by making ETS prices exceed the project CCfD contract price.

2.4.4 Funding gap

Funding gap "awards aid based on the difference between the positive and negative cash flows over the lifetime of the investment, discounted to their current value (typically using the cost of capital)"[207].

As a formula, this may be written as:

$$max\ DEE = DIC - DNR = FG \qquad (5)$$

where:

- *max DEE* is the discounted maximum level of support;
- *DIC* is discounted investment cost;
- *DNR* is discounted net revenue;
- *FG* is the funding-gap.

The key elements of this hypothetical funding gap scheme are provided in Annex 9.

The funding gap approach resolves one weakness expected with the fixed aid intensity support, which is that with aid levels below 100%, the fixed aid intensity support would under-incentivise investment in technologies that do not lower variable costs. With the funding gap approach, the under-incentivisation is eliminated.

2.4.5 Industry overview

Basic statistics for output of steel, cement clinker and ammonia are presented in Annex 10- Annex 12 respectively.

CO_2 emissions by industry are provided in Annex 13.

The CO_2 emissions data, in Eurostat data, is not calculated based on identical product parameters to the output definitions as reported in Annex 10- Annex 12 due to the different purposes of reporting the two types of information. The Team has found estimates that direct CO_2 emissions per tonne of steel production is 1.7-1.9, CO_2 from clinker (in cement production) is 0.53-65 per tonne and CO_2 from ammonia is 0.79-1.8 per ton.[208]

For both steel and clinker, annual "learning" effects for CO_2 reduction are found to be on the order of 1.2%. Figures for ammonia are considered comparable.

2.4.6 Analysis

For each of the three hypotheticals (including the two options for CCfD), an analysis focuses on assessing comparative effectiveness and impact on competition for sector decarbonisation in the long run through to 2050. Decarbonisation predictions focus specifically on reduction of CO_2. They also focus on direct CO_2 outputs. Including indirect CO_2 outputs, which are difficult to predict with a 2050 timeline, could potentially affect the predictions and in particular the relative ranking of different costs per unit of CO_2 abated.

For the baseline, without additional intervention, learning effects will be taken into account. The focus will not be on the detailed technical aspects of CO_2 reduction but on the overall likely impacts on cost-effectiveness and competition.

This baseline – which includes solely maintenance of existing supports for energy efficiency, CHP and RES – suggests that, maintaining current goods output, CO_2 output would fall by about 43%. Expected CO_2 output taking account of learning effects, absent additional state aid support for implementing dramatic innovation, is reported in Table 8.

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[207] See definition in EEAG 2014, definition section 1.3, no. 32.
[208] The higher figure is retained, reflecting broader CO_2 equivalent greenhouse impacts.

Table 8: Baseline industrial CO_2 reduction based on learning effects of 1.2% per annum

Year	Cement	Iron & Steel	Ammonia
2018	73,606	62,199	22,209
2050	39,747	33,587	11,993

Source: UEA.

The transition to decarbonised production for steel plants, cement plants and major ammonia outputs can occur to a high degree over the period to 2050. For steel plants, "practically all major production assets will need substantial reinvestments" with blast furnaces on a cycle of 15-20 years.[209] New technologies may have longer lifespans. Moreover, the movement away from fossil fuels in steel would probably produce a cleaner and potentially longer-lasting infrastructure. For cement and ammonia, in contrast, the plant and process updates may be particularly long-lived. If the transition happens quickly (i.e., within 5 years) the plant lifespan could likely be longer than 2050, so the first investment and technology would likely be the final one, though there could be learning effects within the technology (that will be modelled based on a typical carbon-reduction learning effect in industry). To avoid investments that need decommissioning prior to their economic end of life, care is needed over the technology selection for all new facilities as well as financial guarantees that investments will not be expropriated by long-run regulatory change. The normal course of business innovations (the "learning effect") in industries provide a comparison baseline representing the cost and CO_2 reduction levels that might be expected through normal asset upgrading up to 2050. Furthermore, given the long-range focus of the analysis, it is important to remember that the nature of these approaches is necessarily hypothetical, technologies, costs and effectiveness may change over time and the accuracy of estimates is therefore constrained.

The costs of carbon capture and storage on site is among the 2050 options, though the cost and capabilities of these technologies may still be far from their ultimate frontier. Nonetheless, promising applications were recently announced such as injecting carbon into concrete as it is made.

The main content of the analytical response is a basic simulation. The model includes a sensitivity analysis (from varying key parameters on the costs of improvement for the long-term technologies). An analysis of costs and efficiency looking out to the future, like this one, necessarily includes technological assumptions about future production costs. To the extent these may not be realised, the results are assumption dependent. In energy, for example, the initial long-term predictions of costs of PV turned out to be substantially over-stated.

The core results, without sensitivity analysis, are presented in Table 10 with the three sectors in columns and the three scheme approaches as rows. The CCfD scheme is further divided into two key alternatives, one with multi-industry competitive bidding processes and another with single-industry competitive bidding processes. Results are then reported for impacts of the support programmes on carbon reductions and cost efficiency as a function of core product output, cost of carbon reduction, as well as competitive effects of each regime. More detailed estimates, by technology, are provided in Annex 14 and Table 48 Sensitivity analysis from varying assumptions on costs (+/-25%) is then provided in Annex 14 (Table 49 and Table 50).

Among the CCfD scheme options, the multi-industry competitive bidding processes would be expected to have the efficiency features of reducing CO_2 first in those industries where such reduction can be obtained at the cheapest prices. This would raise the possibility that, if industries do not have sufficiently attractive cost conditions to win tenders, then some reinvestment might occur in old and undesirable technology for industries that are

[209] Material Economics (2019) Industrial Transformation 2020: Pathways to Net-Zero Emissions from EU Heavy Industry, p. 70. https://materialeconomics.com/latest-updates/industrial-transformation-2050.

most expensive to adapt; to the extent that a variety of cost options exist for each industry and overlap, the chance of spreading tenders across industries is higher. Based on the underlying data on cost predictions, the estimated costs by technology currently suggest that, with multi-industry competitive bidding processes, there may be some intermingling of investment across industries, rather than sequential industry by industry decarbonisation, with an initially higher level of decarbonisation in steel.

In contrast, the single industry competitive bidding processes model for CCfD would involve competitive bidding in each industry for CO_2 reduction. It would not allocate the reductions toward those industries where the reduction in cost is lowest, but rather across all industries. This option would be expected to have a higher societal cost for the level of reduction achieved, while resulting in reductions across more industries. Generally, less total reduction would be achieved per amount of support because aid would not be granted first to those technologies that yield the highest CO_2 reduction per unit of aid. Such a conclusion could be moderated if the subsequent technology investment in the industries that did not receive support could end up making investments that produce even more CO_2 than the prior technology, a risk that would be avoided with a single technology industry bidding process. Subject to a common government aid budget constraint across the CCfD schemes, the CCfD multi-industry tender may achieve a higher total CO_2 reduction.

For predicting the extent to which single-industry competitive bidding processes will result in competitive outcomes and pressures for low costs of carbon reduction, one may consider the extent to which production facilities are concentrated at a Member State level. The most likely tenderers are likely to be existing operators who wish to upgrade their old facilities. The more concentrated the industry is at a Member State level, the more likely it is that the tenders will also involve concentrated bidding patterns that may not yield lowest cost per tonne of CO_2 reduced for the government.

Existing analyses of markets in these three industries for competition law purposes tend to focus on the concentration of industries from the perspective of product sales. Steel and ammonia may tend to present a correlation between EU prices and world prices, showing substantial levels of trade between non-EU and EU areas.[210] Cement may tend to present lower levels of trade and more local geographic markets. For the purpose of considering concentration of production for competitive bidding processes for a CCfD arrangement, the geographic markets defined for antitrust investigations provide little information. Member State level information on facilities, including ownership, shows generally high levels of concentration by Member State. Information on facilities present in each Member State for the three industries are presented in Table 9. Facilities can indicate the likely upper bound on bidders in a Member State, but not the lower bound, as they can exaggerate the level of likely competition in tenders, to the extent that many facilities within a Member State share a common owner. Common ownership is therefore examined below.

Production sites for the three industries selected suggest that EU has 25 steel production sites, 47 major fertiliser plants and the 212 cement facilities. The number of states with 0 or 1 facilities is 20 for steel, 18 for fertiliser and 8 for cement. As an indication of steel furnace concentration, it is worth noting that 42% of blast furnaces in the EU are under the control of one owner, ArcelorMittal. In cement, even countries with large numbers of facilities, such as France, are in some respects relatively concentrated, with 43 out of 52 cement facilities under the control of 4 owners.[211] While the geographic focus of cement production may lead to further geographic division of production of cement production within a large country, the risks of ownership effects may, based on concentration figures,

[210] An EC report notes nonetheless that "prices of similar fertiliser products can differ widely between various geographical and local markets, also within the EU". https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/market-brief-fertilisers_june2019_en.pdf.

[211] These figures include grinding plants, while the Table 9 focuses more narrowly on integrated and clinker plants, which are the main producers of CO2 in cement production.

be somewhat lower for cement than the other two industries under study.[212] Estimating the impact of limited competition on tendered costs can be done in a variety of ways. The approach selected relies on an estimate of price impacts from cartels, which suggests a range of 16% to 26% price impacts, with 16% for national cartels and 26% for international cartels.[213] The use of cartel related figures does not imply the existence of cartels in the selected industries; it is intended solely to approximate the impacts of limited competition.

Table 9: Industrial facilities by Member State

Member State	Steel (BF-BOF)		Ammonia	Cement	
	No. of sites	No. of furnaces	(Major Fertiliser Plants)	Integrated Plants	Clinker Plants
Austria	2	5	1	9	
Belgium	1	2	4	4	1
Bulgaria			2	4	
Croatia			1	4	
Republic of Cyprus				1	
Czech Republic	2	5	1	5	
Denmark				2	
Estonia					
Finland	1	2	2	2	
France	2	5	7	30	
Germany	6	14	8	33	
Greece			1	7	
Hungary	1	2	1	3	
Ireland				4	
Italy	1	4	2	34	
Latvia				1	
Lithuania			1	1	
Luxembourg					1
Malta					
The Netherlands	1	2	2		
Poland	2	3	6	11	
Portugal			3	7	
Romania	1	2	1	7	
Slovakia	1	2	1	5	
Slovenia				1	
Spain	2	3	5	35	
Sweden	2	3		2	
Total	25	54	49	212	2

Sources: Steel: UEA from EUROFER (2020), data year 2019; Ammonia: Fertilizers Europe; Cement: The Global Cement Report™, 13th Edition https://www.cemnet.com/global-cement-report, accessed 14/01/21.

Richstein et al (2021) suggest that one option to improve performance of single-industry competitive bidding processes could be to tender on a multi-Member State basis, using

[212] Having said this, it may be worth noting that the cement industry has been particularly prone to cartel activity.
[213] See Oxera and Komninos (2009) "Quantifying antitrust damages: Towards non-binding guidance for courts", Study prepared for the European Commission. p. 91.

cross-border competitive bidding processes procedures to ensure that sufficient bidders would be present to avoid market power in the bidding process.[214] Such schemes would require substantial cross-state cooperation. The bearer of the CCfD guarantees, borne ultimately by the state, would then potentially need to be allocated across participating Member States, subject to the nature of such competitive bidding processes.

The risks of high costs for some industry process investments must still be borne in mind, with the Dutch SDE++ scheme having an administratively imposed subsidy limit of €300 per tonne of CO_2, suggesting a maximum cost of carbon of an order of magnitude greater that in the ETS programme. But according to two reports with estimates of costs for carbon reduction, the cost levels for dozens of different technologies across multiple industries rises relatively smoothly and have many investment options.[215]

Funding gap approaches amount to an administrative accordance of support to cover increased project costs. In such circumstances, in which the firm has better information about minimal costs than the administrator, there is reduced pressure for optimal investments that can create x-inefficiency (inefficiency that may arise in activities, particularly due to lack of constraints or (competitive) pressures for efficiency).[216] In a review of studies addressing x-inefficiency, Button and Weyman-Jones[217] find that the level of inefficiency may lie around 18% on average. This figure is applied to the costs estimates under the funding gap approach, which can be classified as an administratively determined amount of aid until and unless specific technologies have guidance for aid levels. This could more generally be applied to other methods, such as CCfD, when there is no tendering. Fixed aid intensity would not be expected to be subject to x-inefficiency if the aid levels are incomplete (as this incomplete support would provide incentives to invest efficiently).

Table 10: Funding approaches impacts by industry

Funding	Impacts	Steel	Cement	Ammonia
Fixed aid intensity	CO_2 reduction	Low	Low	Low
	Production cost impact	Low	Low	Low
	Cost of carbon reduction	Little or no additional CO_2 reduction beyond baseline learning effect	Little or no additional CO_2 reduction beyond baseline learning effect	Little or no additional CO_2 reduction beyond baseline learning effect
	Competitive effects	No change	No change	No change
CCfD multi-industry tender (Option 1)	CO_2 reduction	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported
	Production cost impact	Production cost up EUR 31-98/tonne steel	Production cost up EUR 37-58/tonne of cement	Production cost up EUR 64-394/tonne of ammonia

[214] Richstein, J, Kruger, M, Neuhoff, K, Chiappinelli, O, Lettow, F and Stede, J. (2021) "Carbon contracts for difference and effective carbon pricing along the supply chain: an assessment of selected socio-economic impacts for Germany.".
[215] See Trinomics (2020) "SDE++ Methodology" and PBL (2020) "Conceptadvies SDE++ 2021 Algemeen, 5 May.
[216] See Leibenstein, H. (1966). "Allocative efficiency vs X-efficiency". American Economic Review 56: 392-415.
[217] See Button, K., & Weyman-Jones, T. (1994). "X-Efficiency and Technical Efficiency". Public Choice, 80(1/2), 83-104.

	Cost of carbon reduction	High cost efficiency of any CO_2 reduction (EUR 18-57/tonne)	High cost efficiency of CO_2 reduction (EUR 60-89/tonne if only cement)	High cost efficiency of any CO_2 reduction (EUR 39-215/tonne)
	Competitive effects	High competition	Low competition (due to being lowest on rank ordering)	High competition
CCfD industry by industry tender (Option 2)	CO_2 reduction	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported
	Production cost impact	Production cost up EUR 31-98/tonne steel	Production cost up EUR 37-58/tonne of cement	Production cost up EUR 64-394/tonne of ammonia
	Cost of carbon reduction	Low cost efficiency of CO_2 reduction (EUR 21-66/tonne due to higher extra margin from lack of competition)	Moderate cost efficiency of CO_2 reduction (EUR 65-96/tonne including moderate extra margin from moderate competition)	Low cost efficiency of CO_2 reduction (EUR 45-249/tonne due to higher extra margin from lack of competition)
	Competitive effects	Low competition	Moderate competition	Low competition
Funding gap	CO_2 reduction	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported	CO_2 reduction dependent on technology, near 100% from those reported
	Production cost impact	Production cost up EUR 37-116/tonne steel	Production cost up EUR44-68/tonne of cement	Production cost up 76-465/tonne ammonia
	Cost of carbon reduction	Low cost efficiency of CO_2 reduction (EUR 25-79/tonne including higher margin for monopoly and x-inefficiency)	Low cost efficiency of CO_2 reduction (EUR 62-97/tonne including higher margin for monopoly and x-inefficiency)	Low cost efficiency of CO_2 reduction (EUR 49-300/tonne including higher margin for monopoly and x-inefficiency)
	Low competition	Low competition	Low competition	Low competition

Source: UEA. Model details provided in Annex 14.

The level of up-front state support may be lower under the CCfD regimes than under the funding gap or fixed aid intensity approaches. This is because the reduced uncertainty on returns of investment allows for a higher level of debt-equity ratio, with some estimates suggesting that the equity needed could fall by a third. This reduction in risk for the private party (and thus reduced need for initial support) may, in some respects, be counter-balanced by increased risk of the CCfD counter-party (presumably the state) at subsequent stages, as the contracting counter-party for the CCfD bears the long-term risk of variation from changes in the market ETS market prices.

One concern that could be expressed about the CCfD regimes is that, by giving investors a very high certainty of the rate of return, the regimes reduce the incentive of investors to act as constant optimisers of their production. In other words, CCfD models could be argued to blunt normal commercial incentives, including the incentive to behave as cost minimisers, given the level of output. Defenders of CCfD could respond that, while the CCfD reduces investment risk with respect to carbon prices, the contracts do not otherwise reduce incentives to lower output of CO_2 when it is socially beneficial to do so, and also do not inherently lower or increase incentives to seek revenue from producing the industrial output.

There is nonetheless risk of windfall profits in some cases, for example if hydrogen prices (or electricity prices) decrease significantly below the prices projected. Similarly, there are substantial risks that remain for investors, for example, if hydrogen is more expensive or if electricity prices are higher than projections. One option would be to further modify CCfDs to account for these windfall/risk possibilities. Such modifications would create increasingly complicated options contracts but could be worth considering, particularly if one believes that economically significant windfall profits are likely to occur (e.g., if one believes that electricity prices are going to continue to fall to the level of variable cost of production from PV, wind and water.)

2.4.7 Conclusions

While industrial decarbonisation shares some of the complexities of energy decarbonisation, for instance the existence of various technologies with different costs, it differs from energy to the extent that: (1) some industrial sectors can be much more economically decarbonised than others, (2) the industrial activities studied produce distinct end products that are generally not substitutes to each other, unlike energy outputs that are substitutes to at least some extent and (3) operating costs do not generally fall post investment, unlike with the wind and PV investments that lowered variable costs of energy production compared to prior fossil fuel technologies.

Comparisons between potential schemes for industrial decarbonisation suggest that investment aid at a 40% of eligible costs is unlikely to achieve substantial incentives for large and expensive investment unless operating costs fall compared to the traditional technology or government-imposed costs on traditional production are raised. Levels much higher than 40% may be necessary to motivate use of this financing mechanism, as the problem remains at 50% or 70%. A 100% support could negate the problem if operating costs remain unchanged for the new technologies compared to the prior technologies.

A more flexible option exists of providing support up to the funding gap for new projects, so that the lifetime relation between investment and operating costs can be considered in the aid decisions. This mode of support has the feature of ensuring that default incentives are not against investment in new and more expensive CO_2-abating technologies. Full support up to the funding gap via project finance risks higher than minimum costs when overseers of aid do not know appropriate cost levels and investors have reduced incentives for full efficiency that can lead to x-inefficiency. This weakness would be offset if aid approvers have a full understanding of efficient cost levels.

Carbon contracts for difference (CCfD) may offer a number of advantages, but also have disadvantages and risks. Advantages include creating a stable long-term investor climate by setting a fixed cost of carbon (and value of carbon reduction). The percentage of equity required for financing a CCfD can fall compared to investment without a CCfD, ultimately meaning that government financial resources can support a larger total volume of investment. Disadvantages and risks include that a CCfD is nonetheless still subject to government (or government entities) bearing the risk of emissions trading scheme (ETS) price variability, market power risks and potential x-inefficiency. A particularly important trade-off on decarbonisation of specific industries against efficiency can be observed in the decision that would be made over whether to set prices of CCfD tenders within an industry or across industries. Steel and ammonia would have limited incumbent competition in single-industry competitive bidding processes as 20 Member States have 1 or 0 incumbent steel facilities, and 18 Member States have 1 or 0 incumbent ammonia facilities. If CCfD tenders run across multiple industries, efficiency will be enhanced, but some industries will likely achieve higher decarbonisation than others due to having technologies with lower costs of achieving CO_2 reductions than others. Ammonia may, in rank order, be decarbonised at a higher cost than steel or cement, at least based on the direct emissions methods used in these estimates (which could alter with full account taken of indirect emissions). The summary of conclusions from Section 2.4 are:

Industrial decarbonisation has fundamentally different economic characteristics from energy decarbonisation. Consequently, aid schemes that worked for energy decarbonisation may not be directly transferable to industrial decarbonisation.

Industrial decarbonisation investments will not yield dramatically lower variable costs of production, unlike PV and wind investments. As a result, partial levels of support via fixed aid intensities for better technologies with increased investment costs will not normally provide substantial incentives for investment.

One alternative is the funding gap approach to project finance which would restore these incentives by ensuring discounted cash flows were not falling from a CO_2-abating investment.

Another alternative is carbon contracts for difference (CCfD) that ensure investors will face a constant and predictable CO_2 price over the primary life of their investment. These may increase the amount of CO_2 available from a given amount of government financing. Single-industry competitive bidding processes will often yield very little competition, as 20 Member States have 1 or 0 incumbent steel facilities, and 18 Member States have 1 or 0 incumbent ammonia facilities. Even in cement, with many more facilities, ownership may remain relatively concentrated with Member States. Multi-industry competitive bidding processes may be more likely to yield competitive outcomes, particularly when there are a variety of technologies possible across many industries in a given jurisdiction holding the bidding process.

3. Study Item 3: Energy-Intensive users

3.1 Introduction

The objective of study item 3 is to answer two research questions. The first question asks to assess, based on a literature review, whether the economic parameters currently used by the EEAG Guidelines 2014 to determine the eligibility of sectors for exemptions from decarbonisation charges for Energy-Intensive Users ("EIU") are the most relevant parameters for the risk of relocation from an economic perspective. In addition, the study should assess whether there are other or any additional criteria that could be used to identify sectors at risk of relocation due to decarbonisation charges. The second question asks to determine the extent to which the profitability of EIUs is affected by different levels of Renewable Energy Sources ("RES") and Combined Heat Power ("CHP") levies ("levies" or "charges") on electricity for a sample of 10 sectors.[218]

This section provides the answers to both questions and is structured as follows:

- Section 3.2 presents the review of the literature along with the assessment of the parameters used by the guidelines to determine eligible sectors and suggestions for additional parameters.
- Section 3.3 describes the data used for the analysis of the impact of levies on the profitability of EIUs.
- Section 3.4 summarizes the results from the descriptive analysis of RES and CHP levies for a sample of 10 sectors.
- Section 3.5 presents the results from the analysis of the relationship between the profitability and RES and CHP levies for the 10 sectors.
- Section 3.6 concludes with the assessment of different levy change scenarios from the perspective of achieving three policy goals: maximising the budget available for RES- and CHP-based electricity generation, limiting the risk of relocation for EIUs and limiting distortions of competition.

3.2 Results of literature review on economic parameters used for EIUs' eligibility for exemption

In the EEAG 2014-2020, sectors at the risk of relocation due to decarbonisation charges on electricity are identified based on **sectoral trade intensity at the EU-level** with non-EU countries, **electro-intensity** defined as electricity cost divided by the gross value added at the sector-level (Annex 3 of the EEAG) or firm-level (Annex 5 of the EEAG), and the more subjective criterion of "economic similarity".[219] The first two criteria are applied in combination, meaning that a sufficient level of both electro- and trade intensity is required for assuming a sufficient risk of relocation at the sectoral level. Study question 3.1 asks to conduct a literature review and assess whether these parameters are the most relevant from an economic perspective.

This section provides an overview of the economic literature with the focus on assessing the relevance of the current parameters, and identifying other potential economic parameters which could be used to determine sectors exposed to the highest risk of relocation. We reviewed available industry studies/reports and academic research, as well as relevant contributions by public authorities and business associations to the consultation for the

[218] The sectors selected for the study are nine manufacturing sectors: manufacture of non-wovens and articles made from non-wovens, except apparel (NACE code C13.95), manufacture of veneer sheets and wood-based panels (C16.21), manufacture of pulp (C17.11), manufacture of household and sanitary goods and of toilet requisites (C17.22), manufacture of industrial gases (C20.11), manufacture of other inorganic basic chemicals (C20.13), manufacture of basic iron and steel and of ferro-alloys (C24.10), aluminium production (C24.42), copper production (C24.44); and one sector from the NACE section J (Information and communication): data processing, hosting and related activities (J63.11).

[219] See footnote 84 of the EEAG.

evaluation of the EEAG in 2019.[220] We cover the literature in English, French and German, although the bulk of the relevant academic and policy research is published in English.

The review is organised as follows. First, we summarise the literature on the impact of higher energy prices, environmental regulation and trade intensity on competitiveness and relocation.[221] Secondly, we present some relevant parameters that are currently not considered to determine the list of eligible sectors. The literature reviewed is referenced in Annex 15.

3.2.1 Environmental regulation, competitiveness and relocation

This section reviews the literature on the impact of higher energy prices and environmental regulation on firms' competitiveness and relocation. Although most of the publications do not discuss the impact of RES and CHP levies per se, any policy that increases the cost of energy might expectedly have similar effects as the introduction of RES levies. Indeed, RES levies and exemptions work by changing the electricity price paid by households and industrial users. We thus start with reviewing the link between electricity prices and relocation choice and competitiveness in Section 3.2.1.1. Next, we focus on evidence for the relationship between prices of energy more generally (i.e. electricity and other energy carriers like gas or oil) and relocation (Section 3.2.1.2). This is motivated by the fact that electricity consumption accounts for more than 50% of total fuel consumption at the global level in all sectors except the construction and non-metallic minerals sector (Sato et al., 2019). This makes the literature studying the impact of higher energy prices on market outcomes of interest relevant to this study item. Section 3.2.1.3 summarizes the literature about the impact of electricity taxes and subsidies on competitiveness. This is relevant, because RES and CHP levies can be considered as such a tax and taxes explain as much as 30% to 70% of the variation in electricity prices across countries worldwide (Sato et al., 2019).[222] The main difference between the RES and CHP levies and general electricity or energy prices are that the levies do not change as often as electricity or energy prices, but are planned in advance and announced by national energy regulators. Levies depend on eligibility for and the magnitude of exemptions applied in each country, which are set by policymakers and differ across countries. Section 3.2.1.4 presents the findings from the literature on environmental regulation and the relocation choice. Most of the studies reviewed in this section discuss the effects of the EU ETS system. Finally, the literature studying the role of trade intensity for the impact of energy prices on competitiveness and relocation risk is summarized in the final Section 3.2.1.5.

Summing up the results of the review, the literature provides some evidence for the impact of higher electricity prices and more stringent environmental regulations on firms' competitiveness and relocation choice for energy-intensive firms, but no significant impact is found for all firms on average. Studies that estimate the average impact of energy prices on various outcomes tend to find no statistically significant effect for the average firm, or at most a small negative effect. However, when restricting the sample to the most energy-intensive firms, most studies reviewed find statistically significant negative effects that are larger in magnitude. This suggests that energy intensity is a relevant variable to consider and its use as a parameter in the EEAG is justified. Fewer studies have focused on the impact of trade intensity, with more mixed results.

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[220] Targeted Consultation for the Evaluation of the Guidelines on State aid for Environmental protection and Energy 2014-2020 (EEAG), https://ec.europa.eu/competition/consultations/2019_eeag/index_en.html (viewed on October 6, 2020).

[221] Our focus here is on the empirical literature. See Carbone and Rivers (2017) for a review of recent papers applying computational general equilibrium (CGE) models to predict the impacts of environmental regulation on international trade, productivity, economic performance and employment. They find that the models in their sample are generally in agreement that in response to unilateral climate policy, emissions-intensive trade-exposed output, exports, and employment will decrease. In particular, if there are increasing returns to scale in emissions-intensive trade-exposed industries, and if the commodities manufactured in different countries are homogeneous, there will be a larger relocation of these industries abroad to unilateral climate policy. Although these results focus on the impact of carbon regulations, one can expect the same conclusions to hold for taxes on electricity prices.

[222] The international energy price data in Sato et al. (2019) covers 48 countries (32 OECD countries and 16 non-OECD countries) for the period 1995-2015.

3.2.1.1 Electricity prices, relocation choice and competitiveness

This section looks at the literature which directly analyses the impact of electricity prices on firms' choice to relocate.

Kahn and Mansur (2013) find that electricity prices are a significant determinant of locational choice for specific electricity-intensive industries such as primary metals, but not on average across all sectors. They use US panel data, disaggregated by country, industry and year, covering the period 1998 to 2009. The authors exploit within border-pair variation in electricity prices and regulation, using county-pair fixed effects, industry-year fixed effects, state-year fixed effects and a vector of county attributes to identify causal effects. The results vary by industry. The elasticity of employment to electricity price is -0.23 and weakly significant for the average industry in the sample indicating a limited impact. However, the estimated elasticity is seven times larger for the most electricity-intensive industry (primary metals). These results support the current EEAG's approach of taking into account electro-intensity for identifying the sectors at risk of relocation.[223]

Equally, Panhans, Lavric and Hanley (2017) find that the effect of electricity prices on firms' relocation decisions is significant. The estimated elasticity of location choice with respect to electricity prices is always less than or equal to one, though. The effect also varies by country. Among the EU countries, the smallest effect was found for Poland (a 10% increase in the price of electricity reduces the share of firms relocating to Poland by 4.6%) and the highest for Austria (a 10% increase in the price of electricity reduces the share of firms relocating to Austria by 8.4%). The authors also compute the effect of a $0.01/kWh increase in electricity prices, which for most countries lead to a 5-6% decrease in their share of relocating firms. The authors use data from Eurofound's European Restructuring Monitor (ERM), which conducts a comprehensive screening of press and online news sources in the European Union to collect information on firms in the EU restructuring and relocating to any country worldwide, for the period 2002–2013. Finally, the results suggest that **the responsiveness of firms to higher energy costs** in terms of the probability of them relocating is about **twice as large for energy-intensive sectors** than for non-energy-intensive sectors, although the point estimate for the interaction term is not statistically significant due to the relatively low sample size.[224] These findings would also support taking into account electro-intensity as a factor for identifying the sectors most likely to relocate due to higher electricity costs.

Finally, a report by Ecofys, Fraunhofer-ISI and GWS (2015) finds that **higher electricity costs lead to a decrease in sectors' competitiveness measured by product prices, exports and production**. They use an input-output model and a trade model to simulate the effect of abolishing the exemption on the renewable energy levy in Germany, assuming a full pass-on from electricity prices to product prices. They get more clear-cut effects than studies based on analysis of historical industry data, which may be due to many different motives firms follow when deciding about relocation rather than changes in electricity prices. Based on their model, for the steel and non-ferrous industries, this would lead to a 17-18% reduction in total production. For the paper and the chemical industry, total production would be reduced by 11% and 4% respectively. Exports and domestic demand are also negatively affected.[225] Overall, the report concludes that higher electricity costs decrease competitiveness for the steel, non-ferrous metals, chemical and paper industries.

Summing up, the evidence analysed in this section suggests that higher electricity prices have a limited impact on the average industry's relocation choice and competitiveness, this does not hold true when accounting for heterogeneity in terms of firm's/sector's electro-intensity. Indeed, the current literature shows that this effect can be relatively large

[223] Khan and Mansur (2013) define electricity-intensity as an index ranging from zero to one, based on NBER productivity data which reports electricity intensity in electricity usage (in kWh) per dollar value of shipments.

[224] Panhans, Lavric and Hanley (2017) create a categorisation based on the DECC (2012) Annual Industrial Energy Consumption Tables for the UK. They create two groupings: one which includes energy intensive industries and another for the remainder of sectors. Energy intensive industries include pharmaceuticals, paper, electronics, chemicals, basic metals, tobacco products and coke and refined petroleum products.

[225] For the textile industry, the authors were not able to model the impact of electricity prices, since the share of firms receiving a subsidy is too low to obtain visible results (around 1%).

for the most electro-intensive industries. This effect is found both in papers relying on a simulation approach and in papers using empirical estimation techniques.

3.2.1.2 Energy prices, relocation choice and competitiveness

This section reviews a complementary strand of the literature, which estimates the impact of energy (which includes electricity, but also other energy carriers like gas or oil) prices on firms' outcomes, e.g. competitiveness, and on industry employment.[226] A lower competitiveness may have implications for relocation decisions in the long run,[227] which makes this literature relevant to the study item. Only few studies exist in the area, as found also by Glachant and Mini (2020) in their review and presented below.

When looking at energy prices more generally rather than electricity prices, Saussay and Sato (2018) find that **relative energy prices have a small but significant impact on foreign investment location**. Their study is based on a global dataset of 70,000 mergers and acquisitions ("M&A") deals in the manufacturing sector covering 41 countries between 1995 and 2014. The authors include country-pair, country-year and sectoral fixed effects, as well as a variable that controls for the existence of a free-trade agreement between a given country pair. Firstly, the results show that a 10% increase in the relative industrial energy price differential between two countries increases by 3.2% the number of acquisitions of firms or assets located in the lower energy price country by firms based in the more expensive country. Secondly, the effect is significantly larger for emerging economies. The impact of relative energy costs[228] is four times larger for OECD to non-OECD transactions (6.9%, significant at the 1% level) than for OECD to OECD transactions (1.7%, not significant at the 10% level). Finally, they show that the effect is heterogeneous across sectors and grows with sectoral energy intensity. For sectors with an energy cost share above 4%, a 10% increase in the relative energy costs leads to an increase in the number of transactions by 9.5%. Overall, these results suggest that higher relative energy prices have a small but significant impact on the location of investment via M&A, which is concentrated among highly energy-intensive sectors and transactions between developed and emerging countries.

Dechezleprêtre, Nachtigall and Stadler (2020) estimate the impact of energy prices on firm exit and employment in the manufacturing sector for OECD countries in the period 2000 to 2014, using a panel fixed-effects approach. They find that **higher energy prices increase the probability of firm exit**. Yet, on average, they have a small positive effect on the employment level of surviving firms. In some sub-sectors (e.g. basic chemicals), even surviving firms suffer and lay off workers as a consequence of higher energy prices and stricter environmental policies. The authors also show that increases in energy prices have a negative and statistically significant impact on total employment at the sector-level. Energy-intensive sectors (e.g. non-metallic minerals, iron and steel) are most affected, while the impact is not statistically significant for less energy-intensive sectors. However, even in highly energy-intensive sectors, the size of the effect is relatively small: in iron and steel production (the most affected sector) a 10% increase in the price of energy reduces the manufacturing sector's employment by 1.9% in the short run. How permanent this effect is in the long term is an open question.

Similarly, Marin and Vona (2019) find that **higher energy prices have a weak negative impact on firm productivity, and increase the probability of firm exit**. They use panel data on French manufacturing establishments over the period 1997-2015, and employ fixed effects and instrumental variable (FE-IV) estimation. Using firm-level data, they find that a 10% increase in energy prices leads to a 1.4% reduction in value added per worker (although this is only weakly significant), and a 1.7% reduction in total factor

[226] On this, see Glachant and Mini (2020), p.37-39, for a recent review of the literature on the impact of energy prices on industrial competitiveness. The authors conclude that the recent studies in this area point towards relatively moderate economic effects.
[227] See for example Koch N. and H. Basse Mama (2019), p. 490.
[228] Relative energy costs are measured as the ratio of energy prices between the acquiring and target country-sector pairs.

productivity. This negative impact is compensated by a 1.3% increase in sales per employee, for example due to increasing margins. Moreover, the authors find a positive effect of energy prices on the probability of exit. The magnitude of the results suggests that historical changes in energy prices between 2000 and 2015 explain about 7.7% to 7.9% of firm exits over the same period.

Using establishment-level data, the authors further show that the negative employment effects are mostly concentrated in energy-intensive and trade-exposed sectors, and for multi-establishment firms. [229] For the average firm, a 10% increase in energy prices leads to a reduction in establishment employment by 0.8%, although the result is only weakly significant. Distinguishing between single-establishment and multi-establishment firms, the authors find no statistically significant effect of higher prices on employment for single-establishment firms, although the effect is negative and significant for multi-establishment firms. To test for heterogeneous effects by energy intensity, the authors interact energy prices with pre-sample average energy intensity. The interaction term is negative and statistically significant at the 5% level, suggesting that **the negative impact of higher energy prices on employment is larger in magnitude for more energy-intensive sectors**. Finally, the results show that a **10% increase in energy prices leads to a significant reduction in employment by 1.1% in trade-intensive sectors**, compared to an insignificant 0.6% in other sectors. These results suggest that trade intensity and energy intensity matter for employment and competitiveness, confirming the relevance of these parameters for the EEAG.

A study by Dussaux (2020) finds that **the impact of higher energy prices differs by firm size**. Using data on French manufacturing firms for the period 2001 to 2016, the firm-level analysis suggests that employment declines as energy prices increase, but only for firms having more than 50 employees. Small firms having less than 50 employees do not reduce employment when the energy price increases. While it is possible that a portion of the small firms exit the market in response to higher energy cost, the authors cannot test for this hypothesis. Additionally, they show that **higher energy prices have no effect on net employment at the industry level, although it generates a reallocation of production and workers from energy-intensive to energy-efficient firms.**

Aldy and Pizer (2015) find that **energy-intensive manufacturing industries are more likely to experience decreases in production and small increases in net imports** than less energy-intensive industries in response to higher energy prices.[230] The estimated elasticity of production to energy prices for industries with an energy intensity exceeding 15% is nearly triple the average elasticity estimate of -0.14. However, the increase in net imports is small in magnitude, which reflects a lack of substitutability with foreign goods or a too short time period considered. The analysis is based on a sample of nearly 450 US industries at the four-digit industry level over the 1979 to 2005 period and simulates the effects of carbon price increase in the short-term (1 to 3 years). These results confirm that the impact of higher energy prices on sector outcomes is small on average, but stronger for the most energy-intensive sectors. This confirms the relevance of the energy intensity parameter of the EEAG.

To conclude, the literature analysed in this section suggests that the impact of higher energy prices is insignificant or small for the average firm and/or industry. However, **for energy-intensive sectors, higher energy prices have a statistically significant negative impact on production, productivity, probability of exit, and employment.** This highlights the importance of considering energy intensity (or electro-intensity) to identify the sectors most vulnerable to higher electricity prices, and supports the use of such a parameter in the EEAG.

[229] Marin and Vona (2019) define trade intensity based on the criteria in the EU ETS: sectors for which trade (import plus export) with non-EU28 countries is larger than 10 percent of the total EU28 production in that sector. Energy intensity is defined as the incidence of energy related costs over value added, as in the EEAG.
[230] The authors define energy intensity as the ratio of all energy expenditures to the value of shipments. To address endogeneity concerns, they employ the 1-year lag of energy intensity in their various specifications.

Table 11 below summarises different definitions of electro-intensity (or energy intensity) that have been used in the literature cited in sections 3.2.1.1. and 3.2.1.2., as well as their advantages and limitations.

Table 11: Measures of electro-intensity used in the guidelines and studies

Study/Guidelines	Definition of electro-(energy-)intensity	Advantages	Limitations
Annex 3 of the EEAG 2014-2020; Aldy and Pizer (2015); Saussay and Sato (2018); Marin and Vona (2019)	Electricity consumption costs divided by gross value added ("GVA") per sector	*Accounts for differences in electricity price (by using electricity costs in € instead of volume in MWh) *Relatively easy to implement (GVA data available at Eurostat; data on electricity consumption at 4-digit sector level reported by countries) *Shows a sector's full exposure to electricity costs changes (and not only due to levies)	*Total electricity cost rather than its increase due to levies *Ignores heterogeneity within a sector
EU ETS State Aid Guidelines May et al. (2020)	The sum of direct and indirect *additional* costs induced by the implementation of the ETS Directive divided by GVA (i.e. share of CO_2 emission cost in GVA)	*Captures additional cost due to ETS allowance price *Relatively easy to implement (GVA data available at Eurostat; direct emissions in EUTL; data on indirect emissions at 4-digit sector level reported by countries)	*Ignores heterogeneity within a sector *Ignores sector's full exposure to electricity costs changes
Khan and Mansur (2013)	Index ranking from zero to one, based on electricity usage (in kWh per dollar value of shipments)	Data available in NBER productivity data	By using electricity consumption volume (MWh), this index does not take into account electricity price differences between sectors and countries.
Panhans, Lavric and Hanley (2017)	Total annual electricity consumption per sector expressed in GWh/year, divided by the number of enterprises in the (2-digit) sector	Data available for the UK from Annual Industrial Energy Consumption Tables.	*As above: does not take into account electricity price differences between sectors and countries. *Absolute consumption volume per firm, not relative to total value added or other costs.

Source: The Authors.

3.2.1.3 Electricity taxes and subsidies and their impact on competitiveness

The literature assessing the impact of RES and CHP levies on competitiveness is limited. One of the few studies assessing the impact of RES levies specifically does **not find any evidence that exemptions from RES levies increase plant competitiveness**, based on indicators such as sales and export share (Gerster and Lamp, 2019). The authors use a matching difference-in-difference estimator, exploiting a 2012 policy change in Germany. The reform lowered the threshold for plants to apply for the exemption from 10 Gigawatt hours (GWh) annual electricity consumption to 1 GWh, which considerably extended the number of exempted plants in the manufacturing sector from 683 to 1,667.

This exemption lowered electricity costs by around 30%. It did not have a statistically significant impact on firm-level indicators of competitiveness like employment, sales, export share and investment. Looking at sector-specific effects, the authors do not find that the exemptions have particularly benefitted the export-oriented industries. Rather, they find that plants with a high electricity-to-sales ratio were the most responsive. They conclude that the policy was not effective and led to a rent-transfer to energy-intensive industries. Note that in this paper, the treatment effect was estimated for the relatively small plants. The existence of a substantial impact of exemptions for larger plants cannot be excluded by the study.

The paper by Flues and Lutz (2015) looks at the impact of electricity taxes on firms' turnover, exports, value added, investment and employment, using a sharp regression discontinuity design. Based on data for Germany, they use the fact that firms that consume electricity above a certain threshold (which was established by legislation) pay reduced marginal tax rates. The threshold decreased from 50 MWh in 1999 to 25 MWh in 2005. The results show **no systematic, statistically significant effects of the electricity tax on firms' turnover, exports, value added, investment and employment**. The authors conclude that eliminating the marginal electricity tax rates could increase government revenues without adversely affecting firms' economic performance. As in the study by Gerster and Lamp (2019), this paper reports a local average treatment effect for plants at the threshold. Therefore, it does not allow conclusions on the effects exemptions may have for plants with electricity consumption above these threshold values.

Interestingly, the EU ETS Guidelines contain provisions allowing State Aid measures to sectors facing an increase in production costs "due to EU ETS allowance **costs passed on in electricity prices**" (European Commission, 2012). A recent report by the Joint Research Centre of the European Commission shows that the impact of this subsidy is limited (Ferrara and Giua, 2020). The results suggest that receiving compensation does not have a significant impact on turnover per worker and value of total assets per worker, but it has a *negative* impact on firm-level turnover, value of total assets and employment. Focusing on the effect of aid intensity for the subset of firms that do receive subsidies, higher compensation amounts do not seem to affect per-worker variables, but they have a marginal positive impact on firm-level economic indicators, e.g. turnover, total assets and employment. These results suggest that firms which do not receive compensation for indirect costs are not substantially worse off than firms which do. Note that this result could be read as a policy success in the sense that the effect of the subsidies exactly off-set the impact of the negative pressure due to competition from countries with lower environmental charges.

Finally, Naegele and Zaklan (2019) find that **indirect electricity costs due to the EU ETS have no impact on trade flows**, using panel data for 2004, 2007 and 2011 for the European manufacturing sector. They allow for lump-sum subsidies (compensation) for electro-intensive firms in their model. The coefficient on indirect electricity costs is statistically indistinguishable from zero in the models of net trade flows. Looking at bilateral flows, the authors do not find robust evidence that the rise in electricity costs caused by the EU ETS affected net imports. Finally, the authors look at the impact of sector-specific transport costs and find no evidence that they played a role in mitigating the effect on trade.

Overall, the literature does not provide clear evidence that electricity taxes and subsidies have a significant impact on firms' competitiveness. Several limitations of the reviewed research may explain why. First, studies which estimate effects for firms close to eligibility thresholds are not able to identify effects for firms far away from the thresholds. In sectors with significant firm heterogeneity, for example in terms of electricity consumption or electro-intensity, the impact of electricity taxes or subsidies on a firm at the threshold of eligibility is likely to be different from the impact on a firm far away from the eligibility threshold. Second, the measurement of effects may be difficult simply because the variation in the level of electricity tax or subsidy was too small to make an observable impact on firms' performance. For example, in France and Central-European countries, effective

RES and CHP levy rates were very low (below 1 cent/kWh). Third, the loss of competitiveness and a potential decision to relocate are mid- to long-term processes and may be out of the short time scope of the currently available studies.

3.2.1.4 Environmental regulation and relocation choice

Environmental regulations can increase energy prices, which has a similar effect as increases in RES levies, as both increase the cost of procuring energy. Moreover, industrial energy prices can be considered a proxy for the stringency of environmental regulations (Sato et al., 2015). For these two reasons, the literature which assesses the **impact of environmental regulations on FDI and relocation risk** is also relevant for RES levies. Multiple studies looked at this impact in the context of the EU ETS system.[231]

A recent report mandated by the European Commission reviews the literature and finds that "up to date there is no hard evidence of carbon leakage caused by EU ETS" (ADE and Compass Lexecon, 2020). However, many of the empirical studies surveyed focused on the first two phases of the EU ETS, and none of the studies reviewed explored the very recent period with a relatively high carbon price. Moreover, from the long-term competitiveness perspective, the lack of evidence may simply be related to the time that such effects take to materialise. Thus, it remains possible that higher production costs due to environmental policy might have a detrimental impact on investment and relocation choice.

Of specific relevance to this study item are two papers investigating **the impact of the EU ETS on outward foreign direct investment (FDI)**. Koch and Basse Mama (2019) find no evidence that the EU ETS had an impact on FDI for the average German firm. They find an effect for a small sample of "footloose" firms, which are paradoxically not in the targeted energy-intensive sectors. A similar study by Borghesi, Franco and Marin (2020) find that Italian multinationals did not increase the number of subsidiaries located in non-ETS countries. However, they found that firms increased their sales in existing subsidiaries in non-ETS countries. These results suggest that the barriers to FDI are difficult to overcome when the firm has to establish its presence abroad for the first time, such that environmental regulation has little effect on the number of new subsidiaries abroad. However, once a firm has already established a subsidiary abroad, environmental regulation has a stronger effect on production taking place in foreign subsidiaries.

Koch and Basse Mama (2019) also look at the degree of geographical mobility of an industry. They find that higher production costs associated with the EU ETS lead to a shift in production to non-EU ETS countries for firms with a permit shortage, operating in combustion plants in sectors (in particular, machinery) which are supposed to be more geographically mobile due to low plant fixed costs. This finding is reinforced by Milani (2017), which shows that industries that are less "footloose" innovate relatively more as environmental regulations increase in stringency. This is consistent with the hypothesis that industries that are more immobile will innovate more than mobile industries when environmental regulations become more restrictive, because it is costly to relocate.

A carbon leakage assessment is done in a very recent publication by May et al. (2020). In preparation for the planned national CO_2 emission trading system in Germany ("Brennstoffemissionshandelsgesetz", BEHG), the paper seeks to identify **sectors in manufacturing, mining and quarrying, which are under the risk of relocation, but not already covered by the EU ETS**. The measure used for this purpose is the share of CO_2 emission cost in gross value added (GVA): when the CO_2 emission cost exceeds 5% of the GVA, the sector is considered at risk of carbon leakage. Applying this methodology, **only five sectors are identified under the risk of relocation**: manufacture of gypsum, manufacturing of malt, manufacturing of oils and fats, manufacturing of ceramic tiles and

[231] The relocation concerns stemming from the ETS allowance price are not the same as the relocation concerns stemming from the RES/CHP levies, since they have different objectives and address different externalities. The ETS allowance price aims to limit greenhouse emissions with their negative externalities, while RES levies aim to fund green energy generation with their positive externalities.

flags, and manufacturing of man-made fibres. The study concludes that any relocation due to the introduction of the BEHG is likely to be limited.

Studies based on interviews also show a limited risk of relocation. Martin et al. (2014a, 2014b) construct a vulnerability score based on 761 interviews with managers. The authors find that the average downsizing risk is low because most firms report that future carbon pricing has no impact on their location decisions. However, the downsizing risk score is significantly higher for the average EU ETS firm relative to other firms, although it does not exceed a 10 percent reduction in production or employment. Yet, there is substantial variation between sectors. After controlling for interview noise, the authors find that other minerals, glass, iron and steel, and cement are the most vulnerable industries, irrespective of employment size at firm-level.

To conclude, the literature available up to now suggests that environmental regulations have a limited impact on FDI and relocation risk. This can be reconciled with the results from the previous sections by taking into account the relatively low stringency of the policies examined, such as the early phases of the EU ETS. It is possible that more stringent environmental regulations would have a more detrimental effect on relocation risk, which would be in line with the results from the literature on the impact of electricity and energy prices.

3.2.1.5 Trade intensity, competitiveness and relocation risk

The literature focusing on the role of trade intensity for the impact of energy prices on competitiveness and relocation risk is limited. A recent study by Marin and Vona (2019) finds that a 10% increase in energy prices leads to a significant reduction in employment by 1.1% in trade-intensive sectors, compared to an insignificant 0.6% in other sectors. Note that this study examined the impact of trade intensity independently of energy intensity, while the approach of the EEAG is to use a combination of both measures.

An earlier study by Martin et al. (2014b) shows that their interview-based measure of relocation risk is not correlated with trade intensity at EU-level. Also allowing for a different impact of trade intensity in firms with low carbon intensity and in firms with high carbon intensity, trade intensity was found to play no role for firm's vulnerability to carbon price. Only when zooming on trade with less developed partner countries including China, that tend to have less stringent environmental regulation standards and which compete with European manufacturing firms, a strong positive relationship between trade intensity and the vulnerability due to carbon price was established. This would suggest that a regionally disaggregated measure of trade intensity might be a relevant parameter for identifying firms at risk of relocation.

Trade intensity might be related to trade costs such as transport costs, and therefore characterise the level of competitive pressure exercised by foreign producers. Looking at transport costs in the context of the indirect emission costs associated with the EU ETS, Naegele and Zaklan (2019) find no evidence that lower transport cost mitigate the negative impact of higher electricity prices on trade flows. This might again be explained by the low compliance costs in the early phases of the EU ETS, as the authors use data for 2004, 2007 and 2011 in their analysis. Using panel data on 128 countries, Shapiro (2016) estimates trade elasticities, which represent the bilateral elasticity of trade value with respect to bilateral trade costs. The sector-specific estimates range from -18.6 (textiles) to -1.6 (chemicals, rubber, plastic), with an overall elasticity of -7.3 for the manufacturing sector as a whole. This large sector variation in these estimates suggests that some sectors are subject to foreign competitive pressure more than other sectors.

Currently the limited available literature shows the relevance of trade intensity on the risk of relocation due to decarbonisation charges. The effect is the strongest for trade with less developed countries including China. There is also significant heterogeneity in the response of trade intensity to the change in trade cost across sectors.

3.2.2 Parameters currently not considered by the European Commission

This section discusses additional parameters which were suggested in the reviewed literature or raised in the public consultation as relevant to identify sectors at risk of relocation.

These parameters could refine or complement the current criteria for eligibility for levy exemptions.

3.2.2.1 Electricity prices of trading partners

First, several papers suggest that **taking into account the level of electricity prices in trading partner countries** would allow a better identification of sectors at risk.[232] The currently used trade intensity with all non-EU trading partners does not account for the differential electricity cost in third countries and thus the competitive threat to firms in the EU. If a sector is very trade-intensive, but trading partners are located in other countries with much higher energy costs, firms in the EU would not be affected as much by increased competitive pressure from those countries and would not have incentives to relocate. To the contrary, if trading partners are subject to low electricity cost, the competitive pressure from those countries could incentivise EU firms to relocate. However, there are theoretical considerations against using such a measure. In the long run, firms choose where to locate conditional on a variety of factors that determine their profitability. These factors include the current and future expected electricity prices. When a firm makes a location decision, the firm therefore takes the current electricity price differential as given. When firms re-optimize their location, the important variable is the marginal expected change in the electricity price relative to its prior baseline, not the current existing price differential of the levels. It is not clear a priori why the effect of an increase in environmental charges in the EU would affect investments in a location with a large electricity price differential stronger that those with a small electricity price differential. To address this issue, it would be necessary to monitor expected changes in relative energy prices between trading partners for each sector.

In practice, taking into account the electricity price differential between trading countries is a challenge. Industrial electricity prices are not easily available: they can be bilaterally negotiated and thus confidential for large electricity consuming firms. In addition, the uncertainty about the accounting standards applied to industrial electricity prices can cast doubt on the adequacy of price data in some countries. Electricity prices can fluctuate over time significantly. Finally, for each sector, a different set of trading countries would need to be considered. This being said, two academic papers suggested ways to introduce some elements of the electricity price differential between trading countries to the currently used EU-wide trade intensity with all non-EU countries. This could be done by **separating trading countries according to their level of economic development** and using trade intensity with less developed countries only. This approach is expected to lead to similar conclusions as when using more detailed information on the charges due to environmental standards. In the context of the EU ETS, Martin et al. (2014b) show that their interview-based measure of relocation risk is not correlated with trade intensity at EU-level. Their analysis suggests that a possible way of tightening the exemption criteria would be to consider exposure to trade only with less developed countries, which include countries such as China and India that tend to have less stringent environmental regulation standards.[233] This proposal is echoed by Saussay and Sato's (2018) finding that the impact of relative energy prices on the number of M&A transactions is four times larger for transactions between OECD and non-OECD countries than for transactions between OECD countries. If trade intensity is to be used as a parameter, **intensity of trade with less developed countries, e.g. non-OECD countries, might be a better proxy for vulnerability than overall trade intensity.** To account for strong competitive pressure from specific OECD countries with lax environmental standards in the EU's geographic proximity (e.g. Turkey), such countries could be added to the non-OECD countries. This trade intensity measure would require turnover, import and export statistics between each EU country and each trading partner at 4-digit NACE sector. These statistics are available at Eurostat. Turnover in million euro at 4-digit level sector can be found in the online data base

[232] Sato et al. (2019) provide a dataset covering sector-level energy prices for 12 industrial sectors in 48 countries for the period 1995 to 2015. Their price indices cover four key types of fuel carriers: electricity, gas, coal and oil. This data could be used to take into account energy prices in third countries.

[233] The full list of countries is reported in the appendix of Martin et al. (2014b). The grouping follows the 2011 UN classification, available online at https://unstats.un.org/unsd/methodology/m49/#ENG_DEVELOPING .

SBS_NA_IND_R2; the value of extra-EU imports and exports from a Member State to a partner country at product level can be found in the Comext database.[234]

An alternative approach could be to create an industrial electricity price index for countries trading with the EU and use it to weigh country-specific trade intensity, higher weight being allocated to countries with a larger electricity price differential relative to the electricity price in the EU. For this approach, it is crucial to use good quality and up-to-date data on industrial electricity prices globally. As discussed above, such data is not easily available. One potential source is the International Energy Agency ("IEA").[235] The IEA collects industrial electricity prices, including for non-OECD countries, through its 'World Energy Prices' dataset. The dataset goes back to 1970 and is updated annually, although for some countries little data is available. Another data source could be the dataset constructed by Sato et al. (2019) with sector-level energy prices for 12 industrial sectors in 48 countries for the period 1995-2015. This dataset is used by academics to study the role of energy prices for international trade. Its main advantage is the availability of sector-level electricity prices, the main disadvantage being limited time coverage (the data end in 2015). Still, both datasets are likely to suffer from general shortcomings on industrial electricity prices mentioned above: confidential nature of bilaterally negotiated prices, difficulty to capture the effects of price volatility and uncertainty about accounting standards in some countries.

3.2.2.2 Capital mobility

Another parameter which was suggested by economists as relevant for identifying sectors at the risk of relocation is **sector's capital mobility**. The paper by Koch and Basse Mama (2019) finds evidence of an effect of the EU ETS on FDI for a sample of "footloose" firms, which were not in the targeted energy-intensive sectors. The "footloose" firms operate in machinery, electrical equipment and automotive parts sectors, which are geographically mobile and can relocate at low cost. At the same time, they have low emission intensity, indicating that they are not the primary addressees of the ETS system. This result is consistent with earlier findings by Kellenberg (2009) and Ederington (2005), but the number of identified firms is small, which likely results from the fact that geographically mobile firms are not heavy (indirect) emitters affected by the EU ETS system in the first place. Thus, the regulatory effort to identify those firms by introducing a new parameter to eligibility criteria might not balance off its benefits.

To introduce such a parameter in practice, data about geographical mobility per sector would be required. Koch and Basse Mama (2019) suggest that parameters like low capital intensity, low transportation cost, low plant fixed cost and/or little scope for agglomeration economies could identify sectors most likely to relocate. Of these measures, capital intensity can be calculated as gross investment in tangible goods per turnover or per employee based on Structural Business Statistics, which is available at Eurostat at a NACE 4-digit sector level.

3.2.2.3 Potential trade

As it is currently defined by EEAG 2014, **trade intensity** does not take into account the effects of potential competition: it ignores any active protectionist measures from third countries, which means that *potential* trade flows and competition in an undistorted counterfactual might be significantly higher than observed.

A possible solution would be taking into account the number of trade barriers imposed by third countries. Trade and investment barriers per country and per type of barrier are recorded in the EU's Market Access Database (MADB) and presented in an annual report

[234] See the Comext data series "DS-059268 - EU trade since 2002 by CPA 2.1", available at http://epp.eurostat.ec.europa.eu/newxtweb/. For more information, see the "User guide on European statistics on international trade in goods", 2020 edition, available at https://ec.europa.eu/eurostat/documents/3859598/12137783/KS-GQ-20-012-EN-N.pdf/f982fc06-3ff8-d37b-298f-9c76c843ae52?t=1608633443374

[235] The International Energy Agency is an intergovernmental organisation. Its membership is limited to countries that are part of the OECD, although it has recently set up an associate membership programme for non-OECD countries such as Brazil, India, and China. Over time, its mission has expanded to cover a wide variety of energy issues.

on trade and investment barriers (see European Commission, 2020 for an example). Trade intensity with third countries that imposed a high number of trade barriers might be given more weight to proxy the actual competitive pressure. Implementing this solution in practise would require selecting the weights for each partner country in each sector. The weight would could also vary over time, so it would need to be revised regularly.

3.2.2.4 Efficiency benchmarks for electro-intensity

Finally, a policy proposal made by Neuhoff et al. (2013) suggests the use of product-specific efficiency benchmarks for electro-intensity per physical unit of output to determine the level of exemptions for decarbonisation charges. This approach not only reduces the risk of relocation per sector but also retains the incentives for individual firms to become more electro-efficient.

In this proposal, the electricity volume used in a production process below a certain, product-specific benchmark (e.g. in terms of MWhs per tonne of aluminium) is exempted from the RES/CHP levy, while any volume above that benchmark level is subject to the full RES/CHP levy. On the one hand, this mechanism provides firms incentives to invest into more efficient technologies and move closer to or even below the efficiency benchmark. This technological change would allow faster decarbonisation of production. On the other hand, the firms within a sector that are electro-efficient as defined by the benchmark are protected from the relocation risk, while firms above the efficiency benchmarks are exposed to that risk only as far as their production technology is inefficient beyond the benchmark.

To implement this approach in practice, product-specific electro-efficiency benchmarks need to be established. For some products, they have been defined in the past as part of the EU ETS price compensation, while for the rest of the products, there is a "fall-back electricity consumption efficiency benchmark" defined.[236] However, developing and updating the benchmarks for the relatively long list of sectors eligible for exemptions in the EEAG guidelines is a complex and time-consuming task and is likely to create significant burden on the authorities. On the other hand, the fall-back option lacks accuracy and was developed to be used as exception rather than a rule.

Section 3.2.2 reviewed suggested additional criteria based on the literature review which could be considered when designing levy exemptions. Levy exemptions should be targeted towards sectors with a comparative energy cost disadvantage (i.e. which trade with countries where energy costs are lower than in the EU), towards sectors with high capital mobility, and towards sectors trading with countries using protectionist measures. A further proposal from the literature is to apply product-specific efficiency benchmarks for electro-intensity per physical unit of output to incentivize implementation of energy-efficient technology and at the same time to restore competitiveness.

Practical implementation of those improvements is, however, difficult. This is due to a lack of reliable and regularly updated data sources, which would allow to measure those criteria across sectors and, thereby, to separate eligible sectors from non-eligible sectors. We make recommendations on how to alleviate these practical limitations. Yet, some question marks on the feasibility of their implementation remain.

3.3 Description of data sources used to analyse the impact of levies on the profitability of EIUs

For the Study, we construct an original dataset that combines data on RES and CHP levies and firms' economic activity.

Electricity consumption volume data per sector, country and year and was provided by the European Commission for the years 2013-2019.

[236] European Commission, "Communication from the Commission amending the Communication from the Commission Guidelines on certain State aid measures in the context of the greenhouse gas emission allowance trading scheme post-2012 Text with EEA relevance", OJ C 387, 15.12.2012, p. 5–13.

Data coverage and availability varies by country. For Germany 2013-2015 and Latvia 2016-2019, electricity purchase volume rather than consumption was provided, they were not used for the analysis. In addition, as the data is not available for Estonia, Italy and Romania, the analysis cannot focus on these countries.

For the sector of "Data processing, hosting and related services" (J63.11), electricity consumption volume was provided by a small number of countries only. Instead, we have used an external sector study[237] to estimate the EU-27 average firm's electricity consumption volume.

Electricity consumption volume data is used to calculate electricity consumption value and the country-, sector- and year-specific electro-intensity for an average firm in the sector.[238]

Electricity price data. We exploit information on industrial electricity prices at the country and year level by electricity consumption band from Eurostat for the period 2011-2018. We use electricity prices without recoverable taxes, but with other taxes and levies, whereby we account for the possibility that levy exemptions might be included in the electricity price.[239]

To translate electricity prices at the country-level into sector-level prices, we use the information on the levy rates. For each sector, we can calculate "effective electricity prices" paid by EIUs (after reduction) depending on the various consumption bands. Each of these prices is calculated as the difference between the country-level electricity price and the sector-specific exemption for that consumption band calculated as described below. The exact construction of effective electricity prices is described in Annex 17.3.

We also select the "most plausible" consumption band indicated by the electricity consumption for an average firm in the sector and use the electricity price for that consumption band as the most plausible price paid by the average firm in the sector.

Sector-specific, most plausible electricity prices are used to calculate the sector's value of electricity consumption, which is in turn used to calculate the average electro-intensity. All steps of the calculation are described in Annex 17.

RES and CHP levy data. Some data on RES and CHP levies were collected in the context of the support study for the Fitness Check for 14 Member States: Austria, Croatia, Denmark, Estonia, France, Germany, Greece, Italy, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia (EU-14).[240] The time period covered by the data is 2008-2018 (but varying by country). The levies were calculated for a hypothetical firm with 20% electro-intensity and for all possible electricity consumption bands. There is no distinction by sectors.

We reviewed and extended the levy data from the Fitness Check study for the purpose of the current study. Annex 16 describes our understanding of the RES and CHP levies and levy exemptions in each country and presents the development of levies for EIUs and Non-EIUs per consumption band in the countries where the levies were adjusted. We verified the eligibility of the firm with the sector's average electricity consumption for RES and CHP levy exemptions in each country and year. Moreover, we calculated sector-specific RES and CHP levies, which were applicable for firms with the sector's average electricity consumption and intensity (with or without reduction, depending on eligibility). These levies are used in the Study. Due to missing electricity consumption data, sector-specific levies could not be calculated for Estonia, Italy and Romania, so that the country coverage of the Study is reduced from EU-14 to EU-11.

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[237] Study on energy prices, costs and their impact on industry and households. Final report for the European Commission. Trinomics, Enerdata, Cambridge Econometrics, LBST, 2020.

[238] Electricity consumption per average firm is calculated as the total electricity consumption divided by the number of firms with more than 20 employees per sector- country and year. Focusing on firms with more than 20 employees allows to avoid the potential downward bias created by many small firms with very low consumption.

[239] We document this procedure and a discussion of other countries in Annex 17.

[240] While the support study provided information on RES and CHP levies for the United Kingdom, the current study focuses only on current Member States.

The levies are analysed in detail for a **sample of 10 sectors** selected by the European Commission primarily based on high levels of electro- and trade-intensity while also taking into account the following additional criteria: good data availability, the inclusion of one telecommunications sector, a mix of sectors geographically concentrated and spread across Member States, economic size, and eligible sectors with existing similar, but not eligible, sectors. The following sectors were selected: manufacture of non-wovens and articles made from non-wovens, except apparel (NACE code C13.95), manufacture of veneer sheets and wood-based panels (C16.21), manufacture of pulp (C17.11), manufacture of household and sanitary goods and of toilet requisites (C17.22), manufacture of industrial gases (C20.11), manufacture of other inorganic basic chemicals (C20.13), manufacture of basic iron and steel and of ferro-alloys (C24.10), aluminium production (C24.42), copper production (C24.44), data processing, hosting and related activities (J63.11). The turnover coverage for each sector is presented in in Annex 19.

Sectoral economic activity data from Eurostat. Sectoral level data on economic activity is available in Eurostat's Structural Business Statistics database. For the years 2011-2018, per sector, country and year, several variables were used.[241] Annex 17.1 summarizes these variables and shows that there exists substantial heterogeneity in economic activity across sectors, both when considering 3-digit and 4-digit NACE Rev. 2 sectors.

Firm- and sectoral-level data from Amadeus. The Study exploits firm-level data on profitability from the Bureau van Dijk's (2010) Amadeus database for the years 2011-2018. We use the unconsolidated version of the Amadeus database.[242] This database contains the name of all subsidiaries of a firm, the country code, the NACE identifier as well as measures of firms' performance and activity. Descriptive statistics for the data from Amadeus are included in Annex 18. This database allows us to look at individual firms' outcomes and in particular profitability EBIT: Earnings Before Interest and Taxes. The data also provides information on firm size, allowing a distinction between average firm outcomes of the different size classes: small, medium and large enterprises.

3.4 Descriptive analysis of RES and CHP levies

This section answers the questions 2 a)-c) of the technical specifications by summarizing the data on RES and CHP levies.

For each country, sector and year, we have calculated the level of full and effective levies paid by an average undertaking in the sector. In Germany, Italy, Poland and Romania, levy exemptions depend on the firm's electricity consumption and/or the firm's or sector's electro intensity. These levies were calculated based on sector-country-year data for electricity consumption volume provided by the European Commission; electricity price paid by the sector available for an average firm's electricity consumption band in Eurostat; sector characteristics like gross value added and the number of firms with more than 20 employees provided by Eurostat. Annex 16 provides information on the legislation of RES and CHP levies in each country, including reductions. Such reductions are dependent on several factors, such as electro-intensity or maximum amounts to be paid as a percentage of gross value added. Annex 17 provides the construction of sectoral economic activity and the measures of electricity consumption, electricity price and electro-intensity.

3.4.1 Countries with the highest and the lowest RES and CHP levy per sector

For each sector and country, RES and CHP levies for a firm with the sector's average electro-intensity and electricity consumption were calculated over time without deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). These sector-specific levies are represented in the figures reported in Annex 19. Based on levy figures for the year 2018, the countries with the highest and the lowest RES

[241] Turnover (in million euro), gross operating surplus (in million euro), value added at factor cost (in million euro), purchases of energy products (in million euro), total number of firms, number of firms with more than 20 employees.

[242] These include information retrieved from unconsolidated financial statements as well as unconsolidated data provided in consolidated financial statements.

and CHP levy were identified. France had no levy in 2018 and was thus not covered by the levy comparison. The following table presents the results.

Table 12: Countries with the highest and lowest RES/CHP levies in 2018 per sector

Sector	Countries with maximum RES and CHP levy (cent/kWh)		Countries with minimum RES and CHP levy (cent/kWh)	
	Levies before reductions	Effective levies	Levies before reductions	Effective levies
Non-wovens (C13.95)	DE (6.95)	DE (6.95)	PL (0.41)	PL (0.33)
Veneer sheets (C16.21)	DE (6.95)	LV (2.58)	EL (0.25)	EL (0.25)
Pulp (C17.11)	DE (6.95)	DE (0.42)	PL (0.41)	PL (0.33)
Sanitary goods (C17.22)	DE (6.95)	DE (6.95)	PL (0.41)	PL (0.33)
Industrial gases (C20.11)	DE (6.95)	DK (0.41)	EL (0.25)	PL (0.06)
Inorganic chemicals (C20.13)	DE (6.95)	EL (0.86)	PL (0.41)	SI (0.11)
Iron and steel (C24.10)	DE (6.95)	EL (2.61)	AT (0.38)	PL (0.25)
Aluminium (C24.42)	DE (6.95)	LV (2.58)	PL (0.41)	DE (0.25)
Copper (C24.44)	DE (6.95)	DE (1.45)	PL (0.41)	PL (0.06)
Data processing (J63.11)	DE (6.95)	DE (6.95)	PL (0.41)	PL (0.41)

Source: Support study. European Commission, Eurostat, and own calculations.

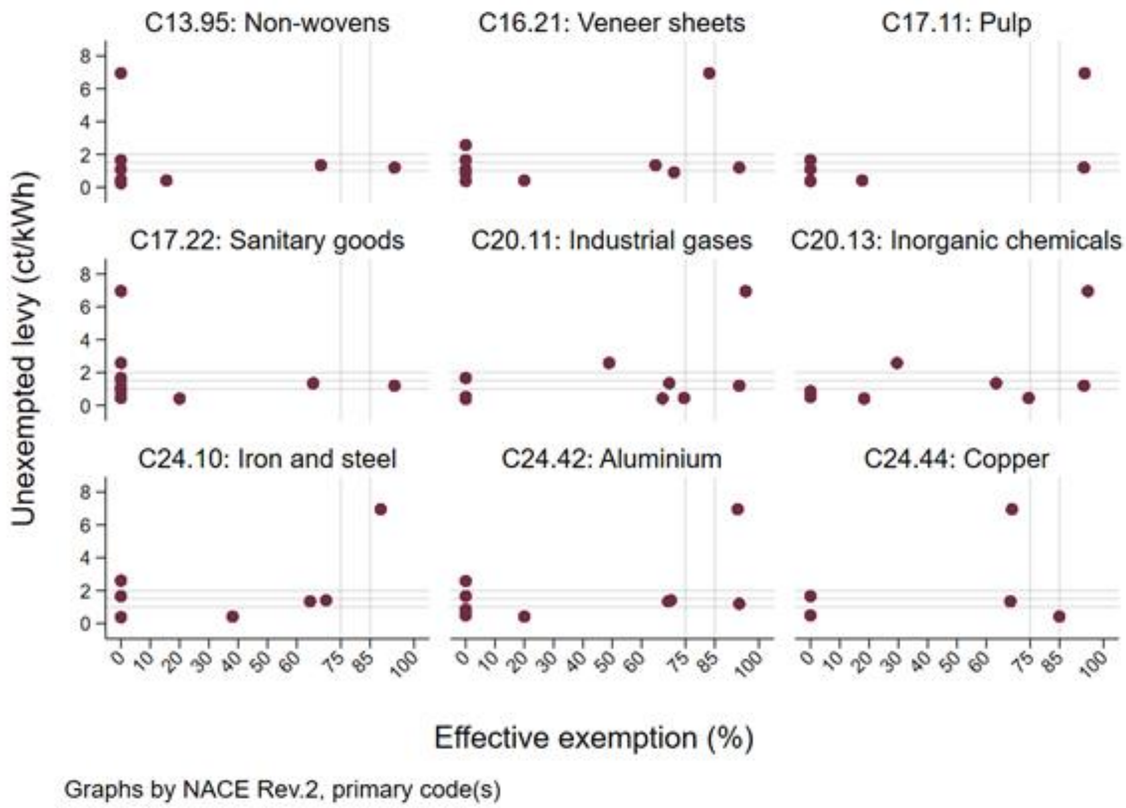
Levies without exemptions were the highest in Germany in all sectors. Countries with the lowest levies without exemptions are Poland (7 sectors), Greece (2 sectors) and Austria (one sector).

Effective levies were the highest in Germany (5 sectors), Greece (2 sectors), Latvia (2 sectors) and Denmark (one sector).[243] Countries with the lowest effective levies are Poland (7 sectors) and Germany, Greece, Slovenia (each one sector). While we did not include Italy due to the lack of information on electricity consumption volume by sector and thus effective levies for an average firm, Italy did face levies before reductions in the range of 4 to 6 ct/kWh before reductions, as demonstrated in Figure 57.

Figure 19 and Figure 20 provide a complementary visualisation of levies before reductions (unexempted levies) and exemptions granted for a firm with the average sectoral electricity consumption and electro-intensity in 2018. One dot in the figure denotes the unexempted levy in cent/kWh and the exemption in % per country and sector. The grey background horizontal lines highlight major levy thresholds 1 cent/kWh, 1.5 cent/kWh and 2 cent/kWh; the vertical lines correspond to major exemption levels 75% and 85%. The difference between the two figures below is motivated by graphical clarity and is explained by respectively the inclusion of Germany (Figure 19) or its exclusion (Figure 20).

[243] Germany had a transition regime in place for 2018 regarding CHP levies. We document this transition regime in detail in Annex 16.

Figure 19: Unexempted levies (cent/kWh) to effective exemptions (%)



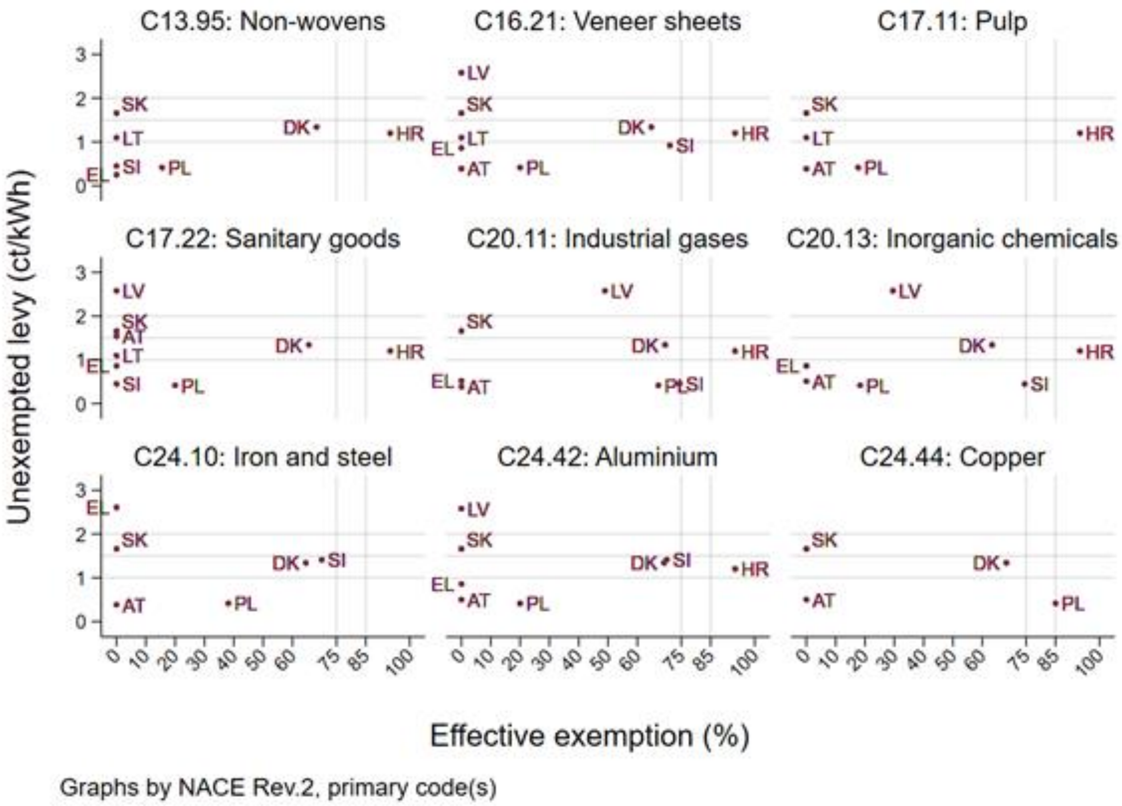
Source: Support study. European Commission, Eurostat, and own calculations.

The highest dot in the vertical dimension, the unexempted levy of 6.95 cent/kWh in Germany, stands out as the largest levy. All other countries in every sector c charge significantly lower levies before reductions. Exemptions in Germany vary significantly between zero for non-wovens and sanitary goods to exceeding 85% for pulp, industrial gases, inorganic chemicals, iron and steel and aluminium.[244]

The following figure focuses on the countries other than Germany.

[244] The reductions that exceeded 85% arose from a levy cap based on the gross value added of the sectors. See Annex 16.6 for more details.

Figure 20: Unexempted levies (cent/kWh) to effective exemptions (%) excluding Germany



Source: Support study. European Commission, Eurostat, and own calculations.

The range of unexempted levies is now significantly reduced to below 3 cent/kWh and the countries with the highest unexempted levy are Greece (iron and steel), Latvia (veneer sheets, sanitary goods, industrial gases, inorganic chemicals and aluminium) and Slovakia (non-wovens, pulp and copper). The lowest levies can be observed in Austria, Poland and Slovenia across all sectors. In the horizontal dimension, the variation in exemptions shows that Denmark has the same large exemption in each sector, while in Poland and Slovenia the exemptions can range from 20% to 85% depending on the sector. Croatia granted exemptions exceeding 85%.[245]

The overview of RES and CHP Levies in Section 3.4.1 brings several insights. Germany had the highest levies and relies heavily on exemptions to bring levies down to levels comparable with other countries for electro-intensive sectors. In five sectors, the exemption brings the German levy from the highest level before reduction to a level comparable to the lowest effective levies in other countries. These strong decreases arise from the eligibility of these industries for a levy cap based on the gross value added ("GVA"). In contrast, the average firm in in C.24.44 (copper) qualified for exemptions based on a percentage of the levy but not for those based on GVA. For the remaining five sectors, effective levies in Germany are still the highest. Similar drops in effective levies can be observed for Italy in Figure 57, as effective levies decrease to approximately 1 cent/kWh, bringing them in line with other Member States. Other countries that have high effective levies are Latvia, Greece and Denmark. The lowest levies can be found in Poland: both levies without exemptions and effective levies reach minimum levels in 7 sectors.

[245] Croatia granted a flat rate reduction for eligible firms. See Annex 16.2 for more details.

3.4.2 EU-11 average RES and CHP levies and their share in the electricity bill

In this section, we address the question of the development of EU-11 average RES and CHP levy and its share in the electricity bill. The EU-11 average levy was calculated by weighting country-levies with their share in the sector's annual turnover. The EU-11 average electricity bill is the turnover-weighted average of electricity price as reported by Eurostat, which includes non-recoverable taxes and levies, but excludes recoverable taxes and levies. For each country and sector, the electricity price was selected for Eurostat's consumption band, which was consistent with the average electricity consumption in the sector. The (country- and sector-specific) consumption band was selected by dividing the sector's electricity consumption by the number of firms in the sector larger than 20 employees.[246] Thus, the levy is calculated for a firm with average electricity consumption in each country and sector.

The following table presents the EU-11 average RES/CHP levy and its share in electricity bill in 2018 in each sector.

Table 13: RES/CHP levies and their share in electricity bill in 2018 per sector

Sector	EU-11 average RES/CHP levy (cent/kWh)		EU-11 average RES and CHP levy share in electricity price (%)	
	Levies before reductions	Effective levies	Levies before reductions	Effective levies
Non-wovens (C13.95)	4.2	4.2	39.3	39.3
Veneer sheets (C16.21)	3.5	0.4	64.2	6.7
Pulp (C17.11)	3.3	0.2	59.7	3.9
Sanitary goods (C17.22)	3.9	3.9	37	36.9
Industrial gases (C20.11)	3	0.1	57.4	2.3
Inorganic chemicals (C20.13)	3.6	0.2	69	3
Iron and steel (C24.10)	3.8	0.3	70.2	4.4
Aluminium (C24.42)	3.8	0.3	70.2	4.6
Copper (C24.44)	6.2	1.3	95.7	20.2
Data processing (J63.11)	2.8	2.8	27.3	27.3

Source: Support study. European Commission, Eurostat, and own calculations.

The first two columns in Table 13 present the levies before and after reductions. The average levy before reductions varies between around 3 to 4.2 eurocents/kWh for eight of the ten sectors. This average levy before reductions is driven by Germany, which often accounts for the largest share of the turnover, and where unexempted levies are around 7 cents in 2018.[247] This result is particularly salient for C24.44 (copper), where Germany has a turnover weight of around 80% among the 11 Member States, increasing the average levy to 6.2 eurocent. In contrast, the J63.11 (data processing) sector had a more uniform distribution of turnover, decreasing the average levy.

The average EU-11 effective levies are more variable. For a majority of the sectors, the average effective levy lies between 0.1 and 0.4 eurocents/kWh.[248] These low levy levels

[246] This measure was used in a study published by the European Commission (Trinomics et al., October 2020).
[247] See Annex 19 for a detailed overview of the turnover in each sector among countries.
[248] Similar to Table 12, six of the 10 industries in Germany qualify for reductions based on the GVA qualifications. C24.44 qualified for a reduction based on a percentage of the full levy.

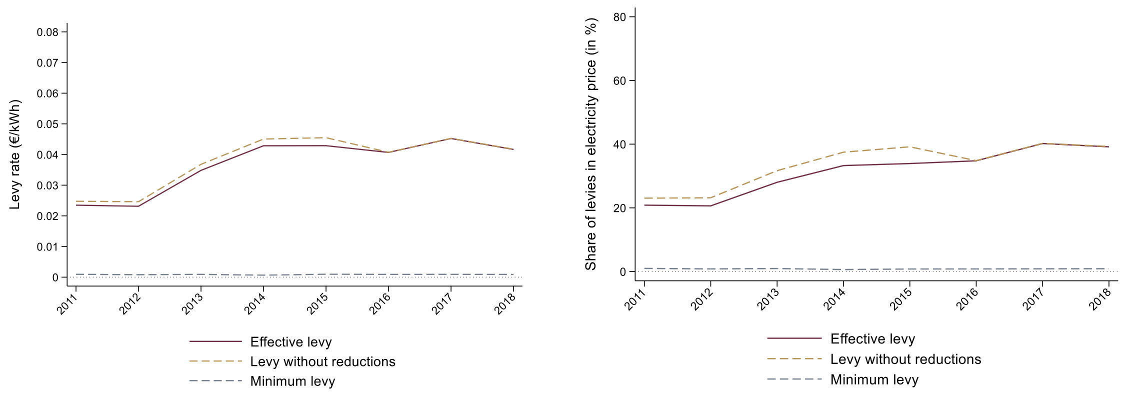
arise from the eligibility for reductions in most of these sectors across the EU-11. In particular, six industries in Germany qualify for exemptions based on GVA. Only for C13.95 (non-wovens) and C17.22 (sanitary goods), the effective levies equal levies before reductions, because the average firm in these sectors does not qualify for exemptions across countries (their estimated electro-intensity was too low). For example, according to our calculations, the firm with the average electricity consumption in C13.95 (non-wovens) had an estimated electro-intensity of 13% in Germany, which was not enough to qualify for exemptions.

Columns 3 and 4 of Table 13 present the share of the levy before reductions and the effective levy in the electricity price. Of note is that the electricity price depends on whether or not a sector is eligible for exemptions. If a sector is eligible for exemptions, its electricity price will be lower. This mechanism explains why C13.95 (non-wovens) has a lower share of the unexempted levy in the electricity price compared to C16.21 (veneer sheets), despite having a similar magnitude of unexempted levies. The shift from shares using the levies before reduction to effective does show a similar story. For the majority of sectors, the share of the effective levy is less than 7 percent. For the non-eligible sectors, the results vary between 20 and 40 percent.

The comparison of levies in Table 13 shows that the exemptions to levies for EIUs reduce the EU-11 average levy significantly when a sector is eligible for exemptions in Germany. This reflects a high level of levies before reductions in Germany and a large share of Germany in a sector's turnover.

The time development of the EU-11 average RES and CHP levy (on the left) and its share in the electricity bill (on the right) is presented in the following figures. We identified three groups of sectors with similar levy development: i) sectors where the firm with the average electricity consumption is not eligible for exemptions in Germany, ii) sectors where the firm with the average electricity consumption is eligible for exemptions in Germany and iii) sectors with eligibility for exemptions in Germany changing over time. Figures for each sector separately are presented in Annex 19.

Figure 21: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of non-wovens and articles made from non-wovens, except apparel

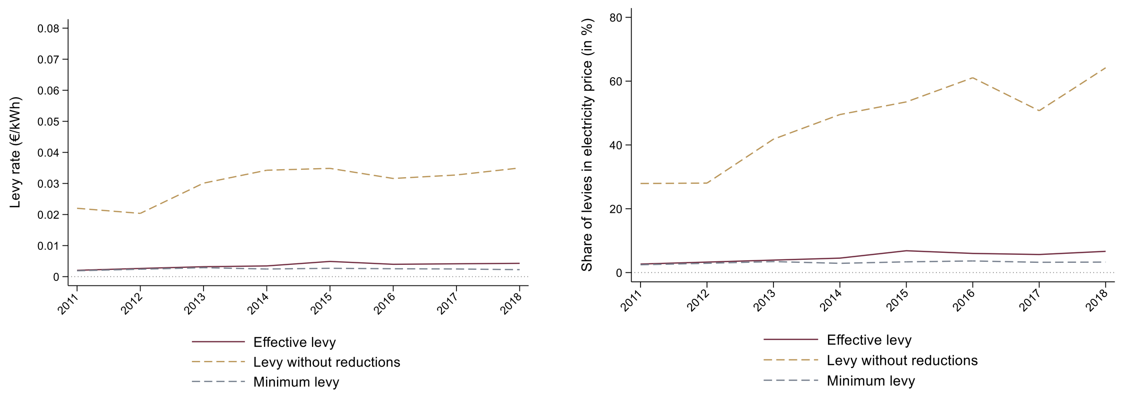


Source: Support study. European Commission, Eurostat, and own calculations.

For the manufacture of non-wovens and articles made from non-wovens, except apparel (C13.95), the EU-11 average RES and CHP levy stayed at a relatively high level above 0.02 €/kWh and it increased over time. It followed closely the development of the levy in Germany, since Germany had a large turnover share in this sector. The difference between the levy without reductions and the effective levy was very small and the gap was driven by countries with a small turnover share (the sector is not eligible for exemptions in Germany). The EU-11 average share of the levy in the electricity price increased from about 20% to more than a half. Another sector with a similar pattern in RES and CHP levy data and their share in electricity price is sanitary equipment (C17.22, see Figure 84 in Annex 19.4.1).

A different type of levy development can be observed for sectors with the average firm eligible for exemptions in Germany: veneer sheets (C16.21), pulp (C17.11), industrial gases (C20.11), inorganic basic chemicals (C20.13), iron and steel (C24.10) and aluminium (C24.42). The figure below shows the example of veneer sheets.

Figure 22: EU-11 average RES and CHP effective levy and its share in the electricity bill in the manufacture of veneer sheets and wood-based panels

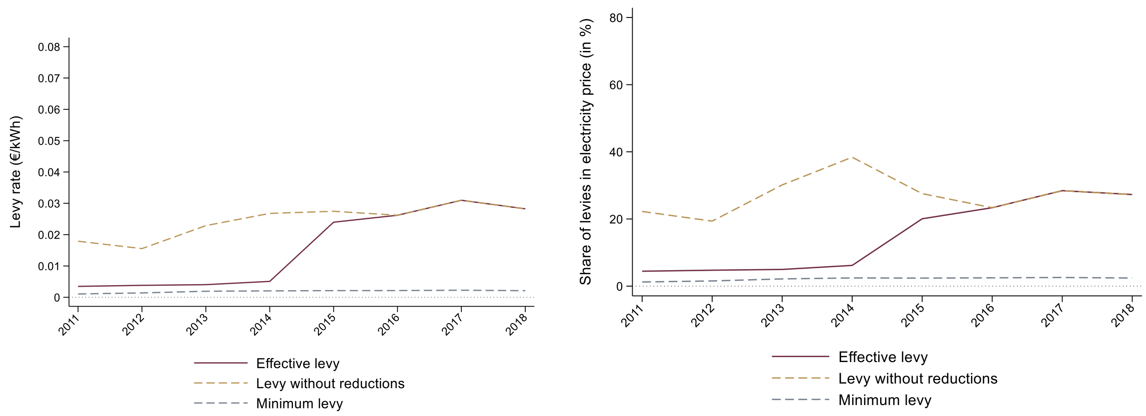


Source: Support study. European Commission, Eurostat, and own calculations.

The EU-11 levies without reductions doubled from about 0.02 €/kWh in 2011 to about 0.04 €/kWh in 2018. However, the exemptions reduced the paid levies very strongly to below 0.01 €/kWh. This is driven by the high level of unexempted levies and high exemptions in Germany. The EU-11 average share of RES and CHP levy in electricity price developed in a very similar way.

The remaining two sectors have a volatile development of RES and CHP levies over time. In data processing (J63.11), the average firm was eligible for exemptions in Germany only in the years 2011-2014. This leads to a large gap between the EU-11 average levy without reductions and the effective levy in the first three years, while both levy types reach a relatively high level of 0.03 €/kWh starting in 2015 as shown in the following figure.

Figure 23: EU-11 average RES and CHP levy and its share in the electricity bill in data processing, hosting and related activities



Source: Support study. European Commission, Eurostat, and own calculations.

The EU-11 average share of levies in electricity price shown in the right figure develops in a similar way and almost reaches 40% in 2018. Similarly volatile are the levies in copper production (C24.44, see Figure 114 in Annex 19.9.1).

Several caveats apply to these findings. First, the EU-11 average share of levies in the electricity price hides enormous heterogeneity across countries. For example, in the above Figure 23, the EU-11 average share of levy reductions in 2013 is about 20% of the electricity price. Though the more disaggregated data shows that this large share of exemptions is driven by only one country. Figure 60 in Annex 17.3 shows country-specific levies and electricity prices for the sector of data processing, hosting and related activities in 2013.

Electricity prices without levies (lines in red in Figure 60) vary significantly between EU-11 countries: the highest price being paid in Greece and the lowest in Germany. The levies come on top and they are not proportional to electricity prices. In Germany, the levy without reductions (grey and beige colour in the figure) is the highest of all countries, but the exemption is also large and brings the total electricity price down to the lowest level among all countries. In the other countries, the total levy is significantly smaller than in Germany and the exemptions are smaller or not at all available. A smaller share of the levy in total electricity price does not mean a smaller electricity cost: In Latvia the levy is larger and has a larger share than in Greece, but the overall electricity price including the levy is higher in Greece than in Latvia.

Another limitation of our approach is that effective levies in each sector are calculated for a firm with the average electricity consumption in the sector.[249] However, if there is a large heterogeneity across firms in terms of electricity consumption and intensity, effective levies may vary significantly within the sector. Third, due to the aggregation to the EU-11 average weighted by turnover, strong shifts in the effective levy may result from a change in eligibility for reductions in just one country or from the change in the country's turnover share.

3.5 Impact of levies on profitability

In this section, we summarise the analysis of the relationship between profitability and RES/CHP levies for each of the 10 sectors. Our main approach is to estimate elasticities of profitability to electricity prices for the 9 manufacturing sectors (Section 3.5.1) and use these to simulate the effect of levy changes on profitability (Section 3.5.2).[250] As a plausibility check, we also employ a static model of sector profitability adjustment resulting from a change in effective levy for all 10 sectors (Section 3.5.3).

3.5.1 Estimation of elasticity of profitability to electricity prices

3.5.1.1 Methodology

In this section, we apply econometric techniques to more closely address the question of the causal impact of RES and CHP levies on profitability. Specifically, as RES and CHP levies are expected to impact profitability by affecting electricity prices, we estimate the direct relationship between the latter and profitability. This is a key ingredient for the simulation of counterfactual scenarios for the RES and CHP. Indeed, the estimates of the elasticity of profits to electricity prices allow us to calculate the change in profits due to changes in electricity prices determined by the introduction of different levies and/or exemptions in counterfactual scenarios.

In order to obtain credible results, i.e. consistent estimates, we need to address the potential endogeneity of electricity prices. In this setting, endogeneity is most likely caused by omitted factors. We address this potential omitted variable issue by introducing several

[249] The electricity consumption for an average firm in a sector is the sector's total electricity consumption divided by the number of firms with more than 20 employees. This allows to avoid a potential downward bias due to the large number of very small firms, which contribute little to the sector's electricity consumption.

[250] This analysis focuses on the manufacturing sector for econometric identification reasons. Hence, the only non-manufacturingsector J63.11 (data processing) is not included in the main analysis, but it is covered by the static model.

fixed-effects, control variables, as well as (non-linear) industry-specific time trends. We therefore estimate the following multivariate panel log-log regression[251]:

$$lnProfitability_{isct} = \alpha_0 + \alpha_1 lnElectricityPrice_{isct} + \beta \ X_{isct} + \mu_i + \ \mu_t + \varepsilon_{isct} \quad (1)$$

where $Profitability_{ijt}$ is the profitability (i.e. EBIT[252]) of firm (i) in a given sector (s) in a given country (c) at one point in time (t). The variables contained in $\boldsymbol{X}$ are controls at the firm and industry-country level that may affect firms' outcomes (for instance industry Value Added, 'VA') and might be correlated to electricity prices[253], and η_i and η_t are firm and time fixed effects, respectively. We also control for industry-specific (at the 2-digit level NACE rev.2) non-linear time trends that might capture the dynamics of common drivers of profitability within an industry. Standard errors are clustered at the firm level to account for autocorrelation.

The main variable of interest is $ElectricityPrice_{isct}$. As discussed above, we do not observe these prices at the firm level. Therefore, we generate different prices, for different electricity consumption profiles (`consumption bands'). This distinction of prices in consumption bands is important as, in some countries like Germany, Poland, and Italy, the effective levies reductions – and hence the effective electricity prices – depend on the firms' electricity consumption. Based on these values, as explained in Annex 17, we construct effective electricity prices based on industry average electricity consumption.

Important for our analysis is to recognise that the profit elasticities to electricity prices (α_1) might be heterogeneous across levels of firm electricity consumption and sectors. We accommodate this heterogeneity by allowing the coefficient α_1 to vary across firms' size classes and industries (the latter discussed in section 3.5.2).

Thus, we estimate the model both on the full sample including all firms and in the three different subsamples of `Small', `Medium' as well as `Large' firms.[254] This step allows considering that firms of different sizes might respond differently to changes in electricity prices. Moreover, this allows us to take into account that specific consumption bands – and the effective prices constructed accordingly – might be more reasonable for specific firm sizes. Indeed, it is likely that larger firms, on average, consume more electricity than smaller firms.

3.5.1.2 Results

We focus on firms in NACE rev. 2 section C, i.e. Manufacturing, which represent the large majority (approx. 63%) of our observations as well as sectors most affected by RES and CHP levy exemptions. In all specifications, we use the measure of electricity prices calculated for the average electricity consumption at the 4-digit NACE rev.2 industries (see Annex 17 for more details).[255] Table 14 reports the results from the estimation of equation (1) based, respectively, on the entire sample (column 1) and subsamples of broadly defined firm size categories (columns 2-4). Summary statistics are provided in Annex 18.

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[251] We choose a log-log specification because both profitability as well as electricity prices have skewed distributions. Moreover, in this model, the estimated coefficients can be easily interpreted as elasticities. However, 15%, 16% and 35% of respectively large, medium and small firms in our sample have negative profits and cannot be used in this specification. To verify whether this sample selection leads to biased estimation we estimate a comparable model for those firms that present losses. Thus, we essentially estimate the profit loss elasticity to electricity prices in a log-log form. In Annex 18, we present the results for this robustness check. Estimated elasticities for unprofitable firms are lower in absolute value but of comparable magnitude.
[252] As explained in section 3.3, EBIT refers to Earnings Before Interest and Taxes provided in the Bureau van Dijk's Amadeus database. Our results are robust to the use of an alternative profitability measure provided in the database, i.e. EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization).
[253] The construction of electricity prices used in the econometrics model is explained in detail in section 3.3 and Annex 17.
[254] We use the definition of firm size provided by Bureau van Dijk. See Annex 17.1 for more details.
[255] In Annex 17 we also report the same estimates using hypothetical electricity prices that correspond to the different electricity consumption bands, ranging from IA to IF, rather than based on the average industry electricity consumption. Moreover, because the average electricity consumption is also not observed but calculated based on several assumptions (see Annex 17), in further robustness checks we report additional elasticity estimates obtained by using electricity prices based on different assumptions on how to measure the average industry electricity consumption.

Our findings can be summarised as follows. First, when we pool all firms in all manufacturing industries, the estimated average elasticity of profits to electricity prices is approximately -0.43. This means that an increase of 1% in the electricity prices implies, on average, a decline of profitability by 0.43 percentage points.

When looking at the three different subsamples for `Small', `Medium' as well as `Large' firms, our findings show the existence of substantial (and significant) heterogeneity in the coefficient estimates across size classes. Specifically, `Large' firms appear to be the most elastic to changes in electricity prices: a 1% increase in the electricity prices implies, on average, a decline of profitability by about 0.54 percentage points. This effect is smaller for medium firms (0.44) and the smallest for small firms (0.29). Thus, the profitability of small firms reacts less to changes in electricity prices than medium firms, and medium firms in turn less than large firms.[256] This is in line with our assumption, and with the literature: larger firms are heavier electricity users and thus more sensitive to price changes therein.

Table 14: Estimation results for `Manufacturing' – EBIT (in log) to industry-averaged electricity prices (in log) – Different firm size classes

	(1) (All)	(2) (Large)	(3) (Medium)	(4) (Small)
ln(Electricity price)	-0.43	-0.54	-0.44	-0.29
	(0.015)***	(0.032)***	(0.023)***	(0.028)***
ln(VA at NACE 2-dig.)	0.24	0.14	0.17	0.36
	(0.014)***	(0.032)***	(0.022)***	(0.022)***
Year FE	Yes	Yes	Yes	Yes
Nace 2dig. trend	Yes	Yes	Yes	Yes
Nace 2dig. trend-sq	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	1,619,333	208,916	628,813	781,604
R2 – adjusted	0.83	0.76	0.66	0.64

Notes: Standard errors clustered at firm level in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on data from Amadeus, Eurostat and the European Commission.

It is worth at this stage to note that these point estimates represent averages across sectors, based on constructed electricity prices with several assumptions. While we believe these results and assumptions to be reasonable, the impact of underlying assumptions is difficult to assess. Moreover, bias due to omitted variables might still affect results. However, while we cannot rule out omitted variable bias, the reported specifications that control for fixed-effects, time trends, as well as industry-level VA explain 83% of the variation in profitability, thereby tentatively indicating that omitted variable bias might be not a severe concern.

Summing up Section 3.5.1, the estimates of the elasticity of profits to electricity prices are used to calculate the change in profits due to changes in electricity prices determined by the introduction of different levies and/or exemptions in counterfactual scenarios. Our

[256] When using prices based on the different consumption bands instead of the average consumption, we observe that the estimated elasticities vary substantially not only across firm size but also depending on the chosen consumption band (see again Annex 17). For instance, estimated elasticities for small firms seem to make the most sense for smaller consumption bands (with the largest elasticity for the lowest consumption bands IA and IB). On the other hand, the highest consumption bands – ID or higher – do not deliver reasonable estimates, as they render a positive estimated elasticity. This can be interpreted as a confirmation that smaller firms tend to fall into smaller consumption bands. Similar patterns can be observed for medium and large firms. In this case, however, higher consumption bands seem to deliver more reasonable estimates for the elasticities, which are at the highest for mid consumption bands (IB-ID). Again, this confirms our intuition.

findings illustrate two main points. First, the adopted approach seems to deliver reasonable elasticities in terms of magnitude. Second, these elasticities vary with firm size, with small firms facing lower elasticities than medium firms, and larger firms facing the largest elasticities.

3.5.2 Simulation model of sector profitability adjustment

The above reported elasticities are the key ingredient of our simulation model, which aims at measuring the change in profits implied by counterfactuals values of the levies and the exemptions.

The analysis in this section is limited to the nine manufacturing NACE rev.2 4-digit sectors selected by the Commission.[257] By doing so, we can allow for more flexibility in our model. In the previous section, we focused on the entire manufacturing sector and estimate one single elasticity for all industries in this sector. Yet, we believe that a great deal of heterogeneity between industries exists and should be accounted for. Indeed, how profits respond to electricity prices depends on the specific production technology used by the firms. These production technologies are heterogeneous across industries, while being more homogenous across firms within one specific industry, especially if we focus on similar firm size categories. Therefore, in this section, we explicitly allow the elasticities to differ across the five NACE rev.2 2-digits sectors encompassing the NACE rev.2 4-digit sectors selected by the Commission for the detailed analysis, namely C13 (Manufacture of textiles), C16 (Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials), C17 (Manufacture of paper and paper products), C20 (Manufacture of chemicals and chemical products), and C24 (Manufacture of basic metals).

Moreover, we drop small firms from our analysis as they represent a very small part of our sample (on average, 2% of total turnover in the nine sectors selected by the Commission). We report both the aggregated elasticities for medium and large firms weighted by the respective total electricity volume consumption, as well as separate elasticities for medium and large firms.

Table 15 reports the results of this additional estimation. As expected, we observe significant differences across sectors, with the smallest elasticities in sectors 17 and 18 (-0.18) and the largest elasticities in sector 16 (-0.63).

Based on these elasticities, we can calculate the changes in profitability corresponding to various counterfactual scenarios. In each of these scenarios, we define counterfactual levies in sector s in country c ($levy_{sc}^{counter}$) that we contrast to the average applicable levy in that sector/country observation as of 2018 ($\overline{levy_{sc}}$). The implied change in levies is then related to the average 2018 electricity price in that sector/country to obtain the percentage change in electricity price that corresponds to a specific counterfactual. The percentage change in profitability due to this counterfactual change in electricity prices results from the following equation:

$$\Delta profitabiliy_{sc} = \left(1 + \frac{levy_{sc}^{counter} - \overline{levy_{sc}}}{\overline{ElectricityPrice_{sc}}}\right)^{Elasticity_s} - 1$$

[257] For the tenth selected sector (data processing), the available data was not sufficient to include it in the estimation of elasticities. This sector is covered by the analysis based on the static model in section 3.5.3.

Table 15: Estimation results for selected 2-digit NACE rev. 2 industries within `Manufacturing' – EBIT (in log) to electricity prices (in log)

	(1) (Large and Medium firms)	(2) (Large firms)	(3) (Medium firms)
NACE=13 × ln(Electricity price)	-0.20	-0.35	-0.13
	(0.077)***	(0.14)**	(0.093)
NACE=16 × ln(Electricity price)	-0.63	-0.53	-0.65
	(0.099)***	(0.17)***	(0.13)***
NACE=17 × ln(Electricity price)	-0.18	-0.12	-0.16
	(0.099)*	(0.16)	(0.12)
NACE=20 × ln(Electricity price)	-0.18	-0.14	-0.19
	(0.066)***	(0.091)	(0.098)**
NACE=24 × ln(Electricity price)	-0.30	-0.27	-0.35
	(0.080)***	(0.11)**	(0.12)***
ln(VA at NACE 2-dig.)	0.19	0.23	0.18
	(0.042)***	(0.079)***	(0.049)***
Year FE	Yes	Yes	Yes
Nace 2dig. trend	Yes	Yes	Yes
Nace 2dig. trend-sq	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Observations	127,215	36,868	90,347
R2 – adjusted	0.81	0.76	0.67

Notes: Standard errors clustered at firm level in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on data from Amadeus, Eurostat and the European Commission.

We develop five sets of counterfactual scenarios. First, we look at the two full levy scenarios: setting all levies at the level of the highest sector-specific full levy (**HI**), or excluding any kinds of exemptions (**NoEX**).

Second, the counterfactuals are calculated as **percentage levy changes** with respect to the *status quo* effective levies (-50%, -20%, -10%, +10%, +20%, +50%, +100%).

Third, we calculate counterfactual levies as **a fixed amount increase** above the *status quo* effective levies (+0.5 ct/kWh, +1 ct/kWh, +1.5 ct/kWh). These changes are assumed to be the same in all countries and sectors.

Fourth, we look at counterfactual effective levies that are **harmonised to be equal across countries/sectors** at various levels: 0.5 ct/kWh, 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh.

Finally, in the last set of scenarios, we simulate the adjustment of two parameters: the **minimum level of unexempted levy above which exemptions are allowed** and/or the **maximum level of the exemption**. We assume that only those Member States using exemptions in the *status quo* also use exemptions with the same eligibility criteria in the counterfactual scenarios. We simulate three threshold levels that trigger the possible exemption: 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh. Further, we simulate exemptions amount of 75% or 85%, which can either be applied to the full levy or only to the part of the full levy which exceeds the threshold. These scenarios have strong "threshold effects", i.e. countries with full levies just above the threshold can grant relatively large exemptions, while countries with full levies just below the threshold cannot grant any exemption.

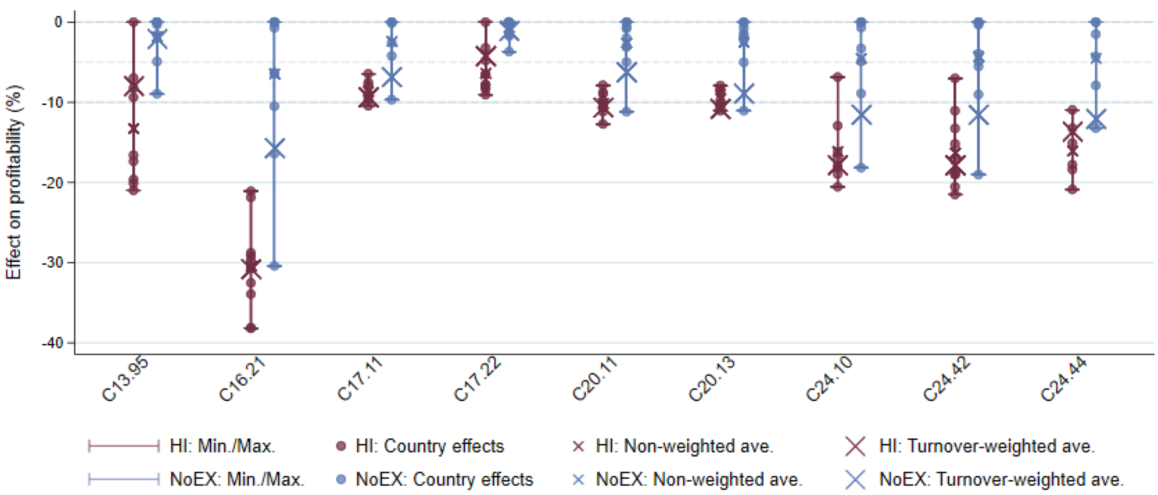
For all counterfactual scenarios, the simulated levy levels are not capped based on GVA. Therefore, if such caps were to remain, the simulated levy changes would be overestimated in the scenarios where levies go up.

Each counterfactual scenario has a different logic and, consequently, produces quite different effects on profitability. This is particularly driven by the fact that, as we discussed in section 3.4.1, effective levies are heterogeneous across countries and sectors in the *status quo*. Therefore, a percentage levy change has a quite different impact from a level levy change. Moreover, in scenarios in which levies are harmonised, sectors will obtain large decreases in levies if they were previously faced with much higher effective levies than the level set by the harmonisation. Countries with unexempted levies below the threshold no longer will provide exemptions, regardless of how strong their subsidies were in the *status quo*. In contrast, eligible sectors in countries where unexempted levies exceed the threshold now receive the exemptions set at the new level. The above examples demonstrate that levy changes in these scenarios lead to very different impacts on profits in different countries and sectors.

Figure 24 represents the result of the first set of counterfactuals: HI and NoEX. For each of the selected sectors, we represent the profit effect in the counterfactual scenario. Each dot represents a country and the crosses represent the turnover-weighted average (large cross) or simple average (small cross) across the 11 European countries in our sample. These two full levy scenarios lead to substantial profit decreases. However, rather than discussing the exact magnitudes, we focus on two high-level findings. First, for each counterfactual and in each sector, we observe substantial cross-country heterogeneity, as the sizes of the intervals indicate in Figure 24. As an example, take sector C13.95 (non-wovens) and scenario HI. The change in profitability varies from 0 to below -20% profitability. The EU-11 weighted average is at approx. -9% and the unweighted average is around -13%.

Second, there are large heterogeneities across sectors. Again, looking at the HI scenario, the non-weighted average is -6.4% in C17.22 (sanitary goods), but reaches around -30% in C16.21 (veneer sheets). Moreover, the cross-country variation (i.e. the distance between the min and max effect) ranges between less than four percentage points in C20.13 (inorganic chemicals) and more than 20 percentage points in C13.95 (non-wovens). Finally, it is important to highlight the relevance of weighting countries according to their share of turnover in that particular industry when constructing average effective levies.

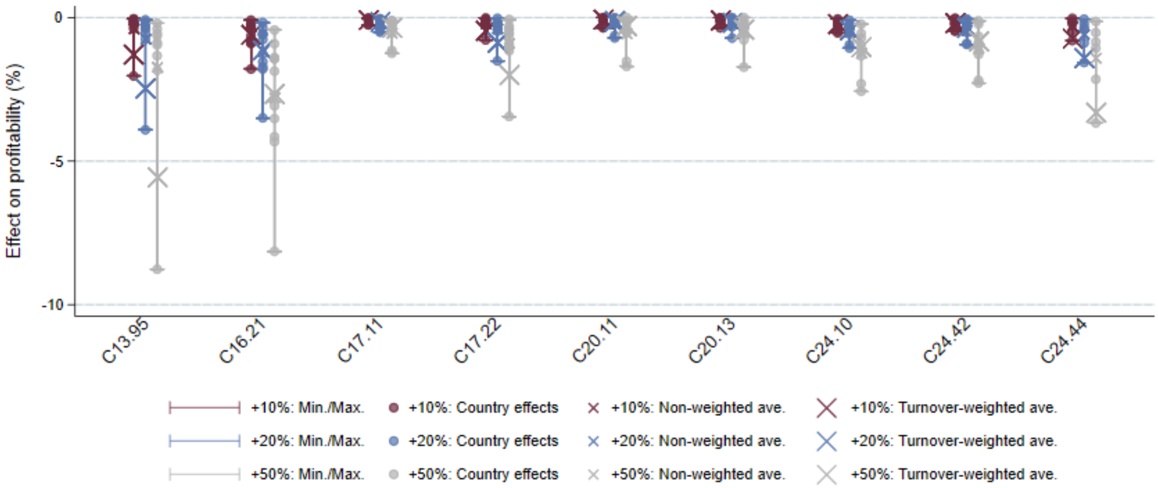
Figure 24: Simulation results (% effect on profitability) across sectors for two scenarios: highest sector-specific levy (HI) and no exemptions (NoEX)



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline.

The second set of counterfactual scenarios show the effect of the increase of effective levies by a percentage.[258]

Figure 25: Simulation results (% effect on profitability) across sectors for effective levy increases by 10%, 20% and 50%



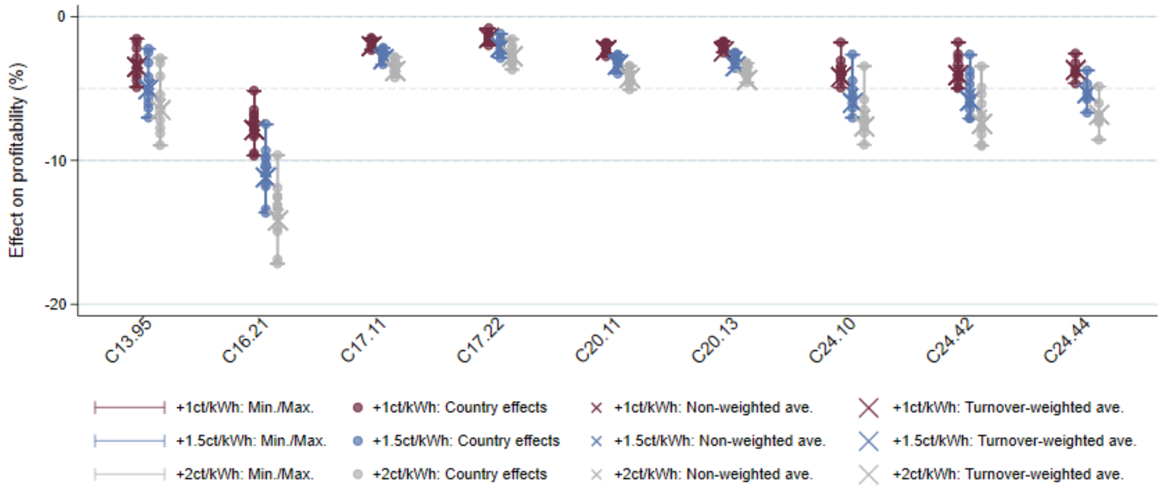
Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline.

In sector C13.95 (non-wovens), the 50% percentage increase in levies with respect to the *status quo* results in a large effect on average sector profitability exceeding -5%. Yet, this large effect is driven by the fact that one country (Germany) has high effective levies (about 7 ct/kWh) when compared to all other countries (mostly around 1 ct/kWh). Thus, the profit effects of percentage changes in levies for Germany are very large. For the other EU-11 countries and sectors, the average profitability effects are below a few percentage points, even for 50 percentage point increases of the effective levies compared to the *status quo*. It is also important to note that these results abstract from caps on payments based on GVA. To the extent firms only have to pay a maximum percentage of their GVA, the current results would overestimate the impacts for firms in sectors that already hit this upper limit.

The third set of counterfactuals simulates profitability changes resulting from levy increases by a fixed amount with respect to the *status quo*: 1 ct, 1.5 ct and 2 ct/kWh.

[258] Figure 25 focuses on the effective levy increase by 10%, 20% and 50%, while the effects for 100% levy increase and 10%, 20% and 50% levy decrease can be found in Annex 19.

Figure 26: Simulation results (% effect on profitability) across sectors for effective levy increases by 1 ct, 1.5 ct and 2 ct/kWh



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline.

In this case we do not observe a large variation in the profit effects across countries. These effects are small in size, ranging from almost 0 in C17.11 (pulp) to a maximum of 7 percentage points in C16.21 (veneer sheets). Thus, in this set of scenarios, the profit effect is not strongly dependent on the effective levies of one single country, as was the case in the previous scenario. The sector with the largest simulated negative effect on profits exceeding -10% is C16.21 and four other sectors have effects exceeding -5%.

The fourth set of scenarios considers setting all effective levies at the same level across countries and sectors. We use four different levels: 0.5 ct/kWh, 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh.[259] The simulated effect on profitability is presented in Figure 27.

Figure 27: Simulation results (% effect on profitability) across sectors for effective levy harmonisation to 0.5 ct/kWh, 1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh

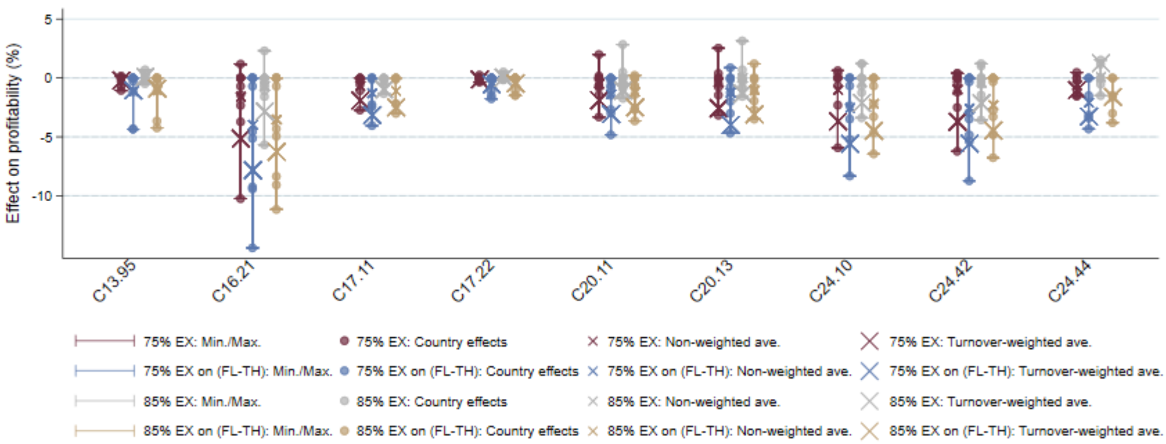
Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline.

[259] The lower levels are chosen to be close to the average and turnover-weighted average of effective levies respectively (0.94 ct/kWh and 0.98 ct/kWh).

The simulated profitability effects can be very large in magnitude and span from over +30% to just below -15%. In the sector C13.95 and C16.21 the heterogeneity of effects between countries is the largest and it comes from the fact that in these sectors the effective levies in Germany and/or Latvia are very high and get reduced by a significant amount, leading to a significant profit increase. For some other countries, however, the effective levies in the *status quo* are lower than the harmonised levy, so that profits decrease in the counterfactual. The large asymmetric distribution of effective levies across countries and sectors drives this result. It is interesting to note that these scenarios can be also seen as showing the effect of asymmetric levy levels in the *status quo*. The profit increase observed for some countries and sectors in the counterfactuals signals that, in the *status quo*, those countries and sectors are facing significant profit reductions due to the existing high levies.

Finally, we analyse the set of scenarios in which exemptions are granted conditionally on the unexempted levy exceeding a given threshold. We further assume that the exemptions are only granted in the counterfactual if they are also granted in the *status quo*. We consider two thresholds: 1ct/kWh (Figure 28) and 2 cents/kWh (Figure 61).[260] The effects depicted in red show the exemptions at 75% of the *unexempted levy.* The effects depicted in blue refer to the exemptions at 75% of the *difference between the unexempted levy and the threshold*. The grey and beige scenarios apply 85% instead of 75% as the exemption.

Figure 28: Simulation results (% effect on profitability) across sectors for exemptions conditional on unexempted levy exceeding 1 ct/kWh and eligibility for exemptions in the status quo



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline. The exemptions are conditional on the unexempted levy exceeding 1 ct/kWh and the eligibility for exemptions in the respective country in the status quo. If unexempted levies were below the threshold, effective levies were set to the unexempted levy. If unexempted levies were above the threshold, exemptions were only applied if the sector already received exemptions in the status quo. Exemptions are calculated based on the unexempted levy or the difference between the unexempted levy and the threshold ("FL-TH").

The effects are limited in sectors where exemptions are hardly used in the *status quo*, such as C13.95 (non-wovens) and C17.22 (sanitary goods). In the other sectors exemptions are used in the *status quo* and stop being used in the counterfactual if the effective levy is below the threshold of 1 cent. In all those sectors and countries profits decrease. The magnitude of the decrease is limited, with the exception of C16.21 (veneer sheets) where profits decrease up to almost 15% in Germany.[261] There are also single countries with profits increasing in the counterfactual: this is the case when the exemption used in the *status quo* was smaller than the exemption used in the counterfactual and can happen

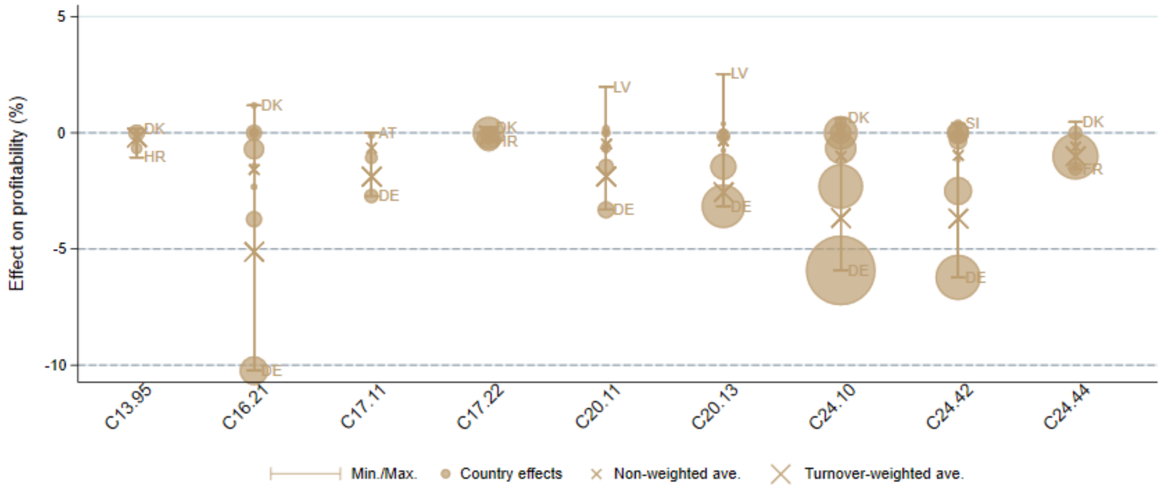
[260] The analysis for the threshold 1.5 ct/kWh can be found in the Annex 19.
[261] The exemptions in this sector in the status quo are larger than 85% due to the GVA cap.

in Denmark, Latvia and Slovenia, as shown in Figure 29, which highlights the turnover of the country in a specific sector and focus on the 75% exemption scenario.

These effects can be compared to the same type of scenarios at the threshold of 2 cents/kWh show in the (Figure 61 in Annex 18).

With the threshold of 2 ct/kWh, the average effects on profitability is limited in magnitude in several sectors. The largest profitability drop of about -10% is calculated for Croatia in C16.21 (veneer sheets). Since the unexempted levy is below the threshold, Croatia is assumed to not grant any exemption in any of the scenarios considered (Figure 62 in Annex 18).

Figure 29: Simulation results (% effect on profitability) across sectors for exemptions conditional on the unexempted levy exceeding 1 ct/kWh and eligibility to exemptions in the status quo with 75% exemption on the full levy



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline. The exemptions are conditional on the unexempted levy exceeding 1 ct/kWh and the eligibility for exemptions in the respective country in the status quo. If unexempted levies were below the threshold, effective levies were set to the unexempted levy. If unexempted levies were above the threshold, exemptions were only applied if the sector already received exemptions in the status quo. Exemptions are calculated based on the unexempted levy.

Our simulations reach two main conclusions. First, the dispersion of the profit effects across countries is driven by the kind of intervention: the highest levy, no exemption and levy harmonisation scenarios generate larger dispersions than scenarios with proportional or level changes in levies as well as when exemptions are conditional on a threshold for the unexempted levy. Second, the level of levies in the *status quo* has a direct implication for the profit effects: sectors with low levies show smaller profit effects than sectors that start with higher levels. This is true in all scenarios except the last set of scenarios in which exemptions are conditional on the full levy to exceed a given threshold.

Section 3.5.2 presented the estimated profit changes for each scenario of levy adjustments. The full levy scenarios of highest levy and no exemptions lead to a substantial decrease in profits. In the other scenarios, the effects on profit vary across sectors both in terms of average effects and across countries, while the cross-country heterogeneity of the effect on profits varies also within each sector. The variation of the impact on profits is thereby driven by three key forces: i) the level of the effective levies in the *status quo*, ii) the cross-country heterogeneity of the *status quo* effective levies in each specific sector, and iii) the nature of the counterfactual (whether full levy, a percentage, a level change or harmonisation). Specifically, the levels of levies in the *status quo* and the cross-country variation of the levies in each sector determine the heterogeneity of the profit effect. Sectors with low levies – and consequently low cross-country heterogeneity – show much smaller profit effects and smaller variation across countries than sectors where only some countries hold high levy levels in the *status quo*. In addition, the variation of the effects on profits across countries is also driven by the nature of the counterfactual: harmonising levies to a certain value generate larger variation in profits than levy changes by a percentage value or by an absolute levy level.

3.5.3 Static model of sector profitability adjustment

Besides the simulation model based on elasticity of profitability, we also set up a static model of sector profitability adjustment. While the static model lacks the richness and flexibility of the regression estimation, it can provide a complementary, short-term view on profitability adjustments due to changes in RES/CHP levies. The static model is a simple accounting exercise whereby we adjust gross operating surplus and turnover by the change in electricity expenditure arising from a levy change. The change in electricity expenditure is calculated as the electricity consumption in a sector, multiplied by the change in the levy. The change in profitability is thus dependent on the electricity volume in a sector, and how it relates to gross operating surplus and turnover.

In this model, a rise in RES and CHP levies increases the cost of electricity, which in turn reduces the gross operating surplus. The cost increase may be passed on to buyers to some extent depending on the sector-specific pass-through. Besides a simple pass-through adjustment, this framework ignores any adjustments in firm behaviour or a change in the market as a reaction to the levy change. This is a strong assumption, which allows to use the model to predict only the very short-term effects of any levy increase. In the mid-term or long-term, firms affected by an increase in levies would be expected to adjust their market behaviour. Another important caveat is that the electricity consumption and electricity price are considered for the industry-country average firm with more than 20 employees. When firms in an industry are heterogeneous in their electricity consumption and intensity, the average effect simulated in our model would not be applicable to the entire sector.

The input data are turnover, energy purchases, gross operating surplus, profitability, electricity price, effective levy and electricity consumption at sector/country/year level. For years when electricity consumption is not available, we estimate it using the share of electricity consumption value in energy purchases calculated for other years. This share is higher than 100% when a sector uses significant amounts of self-generated electricity. We assume that levies are always paid for all consumed electricity, including the self-generated amount. For each sector, EU-11 countries with a positive turnover in the sector were considered. An additional parameter of the simulation is the pass-on of cost increases. Based on pass-on assessment in sector studies,[262] complemented by sector statistics from Eurostat, we selected the most plausible pass-on level for each sector.

For the change in levies, we use changes in effective levies per sector, country and year from the simulation model. As mentioned above, these changes in levies are no longer subject to rules such as caps based on GVA. Detail on the levy changes for each sector and country are available in Annex 19. Using the same levies as in the simulation model facilitates the comparison of the profitability changes resulting from the static model to those simulated with the use of elasticities.

For each sector and country, the average profitability change in 2017 and 2018 was simulated and aggregated to EU-11 average using turnover shares of each country.

The following table summarizes the results. It shows the change in the sector's profitability (weighted average for 2017 and 2018 and EU-11 countries), which is implied by the increase of the RES/CHP levy as defined in each simulation scenario.

[262] Sector Fiches (Annex I) to "Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines", Final report prepared by ACE and Compass Lexecon, October 2020.

Table 16: Changes in profitability (percentage point) per scenario

Sector	Profit-ability	+50 %	+1.5ct	Harm. at 1.5ct	Ex. 85% cond. on 1ct TH	Ex. 85% cond. on 2ct TH	Highest levy	No ex-emp-tion
Non-wovens (C13.95)	9.4	-0.2	-0.2	0.3	0.0	0.0	-0.3	-0.1
Veneer sheets (C16.21)	10.8	-0.1	-0.6	-0.3	-0.1	-0.1	-2.4	-1
Pulp (C17.11)	14.7	-0.1	-1	-0.8	-0.3	-0.3	-4.2	-2.7
Sanitary goods (C17.22)	9.4	-0.3	-0.2	0.4	0.0	0.0	-0.5	-0.1
Industrial gases (C20.11)	18.5	-0.1	-1.4	-1.2	-0.5	-0.5	-5.5	-3.4
Inorganic chemicals (C20.13)	5.8	-0.1	-0.9	-0.7	-0.3	-0.3	-3.8	-2.5
Iron and steel (C24.10)	6.8	-0.1	-0.5	-0.3	-0.1	-0.1	-1.9	-1.1
Alumin-ium (C24.42)	5.6	-0.1	-0.9	-0.7	-0.3	-0.3	-4.2	-2.9
Copper (C24.44)	3.2	-0.1	-0.3	0	0.0	0.0	-1.1	-0.6
Data pro-cessing (J63.11)	15.4	-0.7	-0.8	0.6	0.0	0.0	-2	-0.4

Source: Own calculation based on data from Amadeus, Eurostat and European Commission. Profitability is defined as the gross operating surplus divided by turnover, which are each calculated as the average for 2017-2018. Scenarios "+50%" and 1.5ct increase the effective levy by 50% or 1.5ct/kWh respectively; The scenarios "No exemption" and "Highest levy" set the effective levies in each country and sector to the unexempted levy or to the highest levy within the sector. "Harm at 1.5ct" sets all effective levies at 1.5 ct/kWH. "Ex. 85% cond. on 1ct TH" and "Ex. 85% cond. on 2ct TH" provide percentage reductions in the full levy conditional on the unexempted levy exceeding the respective threshold and the eligibility for exemptions in the respective country in the status quo. If unexempted levies were below the threshold, effective levies were set to the unexempted levy. If unexempted levies were above the threshold, exemptions were only applied if the sector already received exemptions in the status quo. Exemptions are calculated based on the unexempted levy. Levy changes were calculated using the procedure described in section 3.5.2.

The first left column of Table 16 shows the initial level of sector EU-11 profitability in percent (gross operating surplus divided by turnover). All columns to the right show the change in initial profitability for levy changes in selected scenarios.

The first two scenarios with +50% and 1.5 ct/kWh changes of the factual levies show only minor profitability changes in the range of -1.4 p.p. to -0.1 p.p. Harmonisation of levies to 1.5 ct implies limited profitability changes in the range of -1.2 to + 0.6 p.p. In addition, in this scenario profitability increases in some sectors and decreases in others. Another scenario is when 85% reductions are granted for industries that have full levies above a 1 or 2 ct/kWh threshold and are currently eligible for exemptions. In these two scenarios, profitability changes range between -0.5 p.p. and 0 p.p. The reason that the change is zero for industries such as C.13.95 is that they are not eligible for exemptions and thus pay the full levy in the *status quo* and in the counterfactual. Profitability reductions are the largest in the scenario of harmonisation of levies to the highest levy per sector (up to

-5.5 p.p. for industrial gases). Profitability reductions can also be significant in the "no exemption" scenario (e.g. 3.4 p.p. for industrial gases).[263]

The industrial gases, inorganic chemicals, pulp, and aluminium sectors face the largest percentage point decreases in the "no exemption" and "highest levy" scenarios. In the "highest levy" scenario, all levies are very initially low/close to zero given the eligibility of these sectors across countries and they increase to 6.95 ct (highest levy in Germany). As a result, the static model predicts strong decreases in profitability, which are larger than those in the simulation model based on elasticities. Several reasons could explain this difference. First, the static model works in a linear fashion. Its impacts do not decrease with the size of the change. Said differently, the static model does not allow for market adjustments and thus could over-estimate impacts for large levy changes. However, the static model does allow for profitability to become negative.[264] Such changes are not allowed in the regression model due to the logarithm specification, which only allows positive profits.

Second, the static model uses the electricity volume in each industry to calculate changes in profitability. Hence, these sectors, which all have high ratios of electricity consumption to gross operating surplus, are impacted more strongly. While results from the static model need to be interpreted with strong caution, these results do indicate that large levy changes could substantially impact these sectors' profitability due to the importance of electricity volume relative to their profits.

Third, the static model accounts for heterogeneity at 4-digit NACE level, while the elasticity coefficients were estimated for more aggregated, 2-digit sectors. Thus, the results from the static model can differ significantly between the 4-digit sectors belonging to the same 2-digit sector. For example, in some scenarios, we identify significantly stronger effects on profitability in aluminium production than in iron and steel or copper, all belonging to the same 2-digit sector. This is a clear advantage of the static model.

Finally, the static model can estimate effects for the data processing sector, for which elasticity estimates are not available.

Section 3.5.3 developed a static model based on sector-wide electricity cost and profitability data and allows for cost pass-on at the levels suggested by sector studies. The static model confirms the large heterogeneity of effects of levy changes on profits estimated by using profit elasticities. Similarly, profitability changes (reductions) are the highest in the harmonisation scenarios and in the policy experiment which assumes a switch from effective levies to unexempted, full levy levels.

3.6 Impact of scenarios on EU policy objectives

The decarbonisation of the power sector is essential to reach the objective of climate neutrality by 2050 as envisaged in the European Green Deal. One way to support this objective is to collect RES and CHP levies from electricity users to support green electricity generation. There are currently 13 countries in the EU collecting RES and/or CHP levies. In our study, we investigate the effects of adjustments of this policy instrument on firms' profitability in 10 sectors in 11 countries.[265] While there are other sources of financing as well as other policy instruments that could be used to achieve the same objectives, such as environmental taxes or industry regulation disincentivising non-environment friendly behaviour, we abstract from assessing these other potential policy choices and focus on changes in the effective RES and CHP levy levels.

We consider the following three criteria to evaluate outcomes in the light of the objective to reach climate neutrality by 2050 in the EU:

[263] This impact is mostly driven by Germany, where the changes in levies in the no exemption are substantial.
[264] For example, France's profitability in the pulp sector decreases from 2.5% to -2.9%.
[265] Only nine sectors were evaluated using the regression framework. Sector J63.11 ("data processing") was evaluated using the static model in Section 3.5.3.

i. Collecting maximum possible budget to support RES and CHP electricity generation to support the EU Green Deal. This implies that the simulated levies should increase. To operationalize this concept, we delineate three categories for the impact of levies changes on the collected budget: positive (levies in all countries and sectors increase), negative (levies in all countries and sectors decrease) and mostly positive impact (levies in most of countries and sectors increase).;
ii. Limiting distortions of competition between EU countries. This implies that the heterogeneity of the simulated levies should be limited. To operationalize this concept, we delineate three categories for the impact of levies changes on the collected budget: positive (levies become less heterogenous across countries), negative (levies become more heterogenous across countries) and limited impact (heterogeneity of levies across countries changes in relative terms).;
iii. Reducing the risk of relocation of industries away from the EU to third countries without RES and CHP levies. This implies that the simulated profitability decreases resulting from the levy change in each relevant sector should be limited. To operationalize this concept, we delineate three categories for the impact of levies changes on the risk of relocation outside the EU: limited (changes in profits between zero and five percent), moderate (five and ten percent), or high (higher than ten percent). These specific thresholds should only be taken as an example for a possible quantification of the effects.

The following table summarises our assessment of the impact of levy changes on each criterion for a selected subset of scenarios considered in this study for the nine sectors used in the simulation model. A full evaluation of all scenarios can be found in Annex 18.

Table 17: Assessment of scenarios for country-sectors ("C/S") in the nine sectors and EU-11

Scenario	Maximising budget for RES and CHP support	Minimising distortion of competition within the EU	Minimising risk of relocation outside the EU
No exemptions	Positive impact	Unclear	High negative impact in 8C/S, moderate negative impact in 9 C/S and limited negative impact in 30 C/S, no impact in 34 C/S.
-50%/-20%/-10% effective levy decrease	Negative impact	Positive impact	High positive impact for 2 C/S, moderate positive impact for 2 C/S. Limited positive impact for the remaining C/S.
+50% effective levy increase	Positive impact	Negative impact	Limited negative impact for 77 C/S, moderate impact for 2 C/S
+1.0 ct/kWh effective levy increase	Positive impact	Limited positive impact	Limited negative impact for the majority of C/S. Moderate impact for 11 C/S
Harmonisation of effective levies to 1 ct/kWh	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate positive impact in 1, high positive impact in 3 and moderate negative impact in 4 C/S
Harmonisation of effective levies to 2 ct/kWh	Mostly positive impact	Positive impact	Limited impact for the majority of C/S, moderate positive impact in one, high positive impact in one, moderate negative impact in 22 and high negative impact in 6 C/S
Cond. ex. with TH of 1 ct/kWh and 75% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 2 and high negative impact in 1 country/sector
Cond. ex. with TH of 1 ct/kWh and 75% ex. on full levy-1ct	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 7 and high negative impact in 1 country/sector

Cond. ex. with TH of 1 ct/kWh and 85% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in only 1 country/sector
Cond. ex. with TH of 1 ct/kWh and 85% ex. on full levy-1ct	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 4 and high negative in 1 country/sector
Cond. ex. with TH of 2 ct/kWh and 75% ex. on full levy-2ct	Mostly positive impact	Positive impact	Limited impact for the majority of C/S, moderate negative impact in 11 and high negative in 5 C/S

Source: Own calculations based on data from Amadeus, Eurostat and the European Commission. All scenarios assume changes of effective levies. Not all sectors are present in every Member State of the EU-11. The nine sectors in the EU-11 add up to 99 country-sectors, but only 81 country-sectors had information available on electricity consumption and levies. See Section 3.5.2 for more details on the scenarios.

This assessment highlights the trade-offs between various scenarios for the impact on different policy objectives. A larger budget for RES and CHP support can be only achieved if Member States themselves decide to increase the *status quo* levies. Yet, the distortion of competition resulting from different effective levy levels across EU countries, which already exists in the *status quo*, might even increase in some scenarios. For instance, competition distortions increase when levies are increased proportionally (by a % share). An increase of all levies by an absolute amount reduces the heterogeneity of levies across countries per sector. Moreover, while the latter scenario decreases the distortions in percentage terms, it does not resolve the existing distortions in competition in the *status quo*.

These distortions can only be reduced by explicitly harmonising the effective levies across countries within sectors. When levies are harmonised to the highest possible levy across sectors, a strong negative impact on the profitability of most sectors is to be expected, with substantial risks of relocation. When levies are harmonised to a fixed levy level, competition distortions, i.e. the differences in effective levies, are reduced to the minimum. However, effective levies would decrease in countries where *status quo* levies are particularly high and above the counterfactual harmonised levels. Thus, the overall effect on the budget derived from the levies depends on the weight of each country in the specific sector.

The scenarios with conditional exemptions allow resolving these trade-offs to a significant extent: they provide incentives to the Member States to increase levies and, thus, the budget available to support the EU Green Deal; they reduce the *status quo* heterogeneity in levies; and they are, according to our estimates, unlikely to cause economically substantial reductions in firms' profitability, at least in most countries and sectors, minimizing the risk of relocation.

While we focus on a sub-sample of sectors and countries in this study, one should bear in mind that changes in levies will possibly affect the entire EU economy. The scenarios discussed above, for instance, might have substantial effects on firms' profits on those EU countries that do not collect levies, in case of participation. In addition, less electro-intense sectors, which are not considered in our report, might be negatively affected too. However, the negative effect on profitability should be expected to be less pronounced than for the electro-intensive sectors analysed in this report. Indeed, the majority of firms in non-electro-intensive sectors are expected to be less dependent on electricity and, thus, their profitability is expected to react less strongly to higher electricity prices triggered by higher levies.

To conclude our assessment of the different simulated scenarios, we evaluate the different scenarios based on how they help reaching the objective of climate neutrality by 2050 as envisaged in the European Green Deal by increasing the budget available for RES and CHP. From this perspective, the higher the levies, the more likely the climate neutrality goal will be reached.

All levies set to the highest full levy across countries in the sector (highest levy). This scenario implies a significant increase of levies for most Member States and the simulated profit decreases have the largest magnitude, so the risk of relocation electro-intensive sectors outside of the EU is likely. Such significant risk may outweigh the fact that such a policy would substantially boost the budget available for RES and CHP and it would completely remove the heterogeneity in levies within the EU, thus eliminating competition distortions.

No exemptions to full levies for EIUs, whose competitiveness is significantly affected by increases in the electricity price. [266] This scenario would significantly increase levies and at the same time negatively affect profitability in those sectors and Member States in which, in the *status quo*, nominal levies are high but relatively high exemptions are granted. EIUs in those Member States would face a significant negative impact on their market outcomes when effective levies, and thus electricity prices, substantially increase.[267] Again, this significant negative impact on the profitability of EIUs may outweigh the substantial boost to the budget available for RES and CHP.

Levies increased by a 10%/20%/50% of *status quo* effective levies (relative increase).[268] Under these scenarios, the impact of the percentage increase in levies depends on the level of the levies in the *status quo*. As a result, for Member States with high levies, large percentage increases could have a strong negative impact on profits and competitiveness, but also strongly increase the budget available to RES/CHP. In contrast, for Member States with low levy levels in the *status quo*, these scenarios only trigger a low electricity price increase, a small increase in the risk of relocation and a small increase of the budget available for RES and CHP. Thus, these scenarios are not likely to substantially increase the budget available for the RES and CHP electricity generation and help reach the goal set by the EU Green Deal.

Effective levies increased by a certain amount (1, 1.5, 2 ct/kWh) above *status quo* levies: Such scenarios would expand the budget available for RES and CHP electricity generation without increasing the heterogeneity of levy changes, and, for most of the sectors, without reducing the profitability to a significant extent (especially the lowest increase of 1 ct/kWh, which leads to effects on profitability below 5% in all but one selected sector).

Harmonisation of effective levies to a fixed levy level of 0.5, 1, 1.5 and 2 ct/kWh: These scenarios lead to both increases and decreases in the budget available for RES and CHP depending on the *status quo* levy levels across sectors and Member States. For example, there would be a decrease in the budget available for RES and CHP electricity generation from sectors with effective levies above the harmonisation level, such as unexempted sectors in Germany and Latvia. The opposite result holds for sectors/countries with effective levies below the harmonisation level.

Exemptions conditional of the full levy exceeding a threshold (1 ct/kWh, 1.5 ct/kWh and 2 ct/kWh, 75% or 85% exemptions applied to the full levy or only to the part of the full levy which exceeds the threshold) and given only when exemptions are granted in the *status quo*. In these scenarios, the budget available for the RES/CHP electricity generation always increases in all sectors and Member States. The increase is the largest in the scenario with the highest threshold and where the lowest exemption applies only to the part of the levy which exceeds the threshold.

The evaluation of the likelihood of these scenarios are subject to several caveats. First, there are a range of important factors that determine the rate of transition to climate neutrality in 2050, which we do not consider in this analysis. Examples of such factors are the supply of fossil fuels or the rate at which renewable energy technologies become competitive. This last factor could arise due to learning by doing or additional technological breakthroughs. As a result, it is impossible to say how much subsidies would be needed for a transition to climate neutrality in 2050 based on our analysis. In addition, the required subsidies amount depends on the use of other potential policy instruments such as

[266] This scenario applies only to Member States which give exemptions. This scenario can either be seen as reflecting a decision of the Member States or a decision of the EU Commission.
[267] Firms might have varying eligibility within a sector, so the shift would depend on the eligibility distribution.
[268] We understand Member States cannot increase the effective levy and we rather consider this to be the overall effect of increasing the unexempted levy and adjusting the exemptions.

environmental taxes or industry regulation. This is important as we do not consider such potential policy choices.

Besides these general caveats, there are also important qualifications regarding the extrapolation of results in this study. First, estimated levies are based on several assumptions which we document in more detail in Section 3.4. One of the most important is that estimated levies are constant for similar-size firms. However, firms within the same industry might face different levies due to varying levels of electro-intensity or GVA.[269] Second, the sectors analysed in the study often entail a significant share of EIUs that are eligible for exemptions. Their effective levies might thus be substantially lower than the levies for other industries, which might therefore be significantly affected by levy changes. Third, as has been illustrated in the previous sections, there are important differences in the levy levels among Member States. Several Member States, such as Germany, Italy, and Latvia, have considerably higher levy levels than others. Thus, the policy choices in these countries are likely to be different than in countries with low levies.

Section 3.6 compares different scenarios of levy changes and assesses the trade-offs between three main policy objectives: i) collecting the largest possible budget for RES and CHP to support the European Green Deal, ii) limiting the distortion of competition within the EU existing in the *status quo* due to different effective levy levels across countries and iii) limiting a potential negative impact on profits generated by levy changes, which could trigger relocation of firms outside the EU in the long term. We find that scenarios which set the exemptions conditional on the full levy exceeding a certain threshold are best in resolving the trade-offs between these policy objectives. This option assumes levy exemptions only for countries that exhibit a full levy level above the threshold in the *status quo* and for firms eligible for exemptions in the *status quo*. Such a scenario would allow an increase in budget available and reduce the current heterogeneity in levies – thus, the competition distortions. In addition, according to our estimations, it would be unlikely to cause large profitability reductions in most countries and sectors, limiting the risk of relocation.

[269] For example, the average firms in six out of the ten industries in Germany benefit from the GVA restriction in 2018. As a result, they face levies below 0.5 cent/kWh. In contrast, the average firm in Copper is (just) eligible for reductions based on electro-intensity, but not based on GVA, and thus faces a levy of 1.4 ct/kWh. The representative firms in the remaining three sectors do not qualify for any exemptions and pay the unexempted levy. See Table 12 and its description for more information.

4. Annexes

Study item 1

Annex 1 Further evidence on the literature review

This section provides complementary results of the literature review on study item 1.

Annex 1.1 Measurement of cost-effectiveness

While most of 1.2.1 is based on the available evidence on the measurement of cost-effectiveness of renewable energy schemes or CO_2 emission reducing technologies, this annex describes which additional metrics are used when assessing energy saving programmes or technologies. The annex provides also further evidence on the potential benefits of overlapping RES support with ETS.

Annex 1.1.1 Cost-effectiveness of measures to reduce energy consumption

When assessing the cost-effectiveness of support measures aimed at reducing energy consumption rather than the CO_2 emission for a given level of consumption, policymakers may also use different metrics than € per abated tonne of CO_2. This annex deals with the measurement of cost-effectiveness of combined heat and power technologies (CHP) and energy efficiency programmes.

As per the 2014 EEAG, CHP means the simultaneous generation in one process of thermal energy and electrical and/or mechanical energy. While CHP avoids the fuel consumption needed to produce heat from a different technology, it uses fuel to produce both thermal and electrical and/or mechanical energy output: this may lead to an increase of on-site fuel use and must be considered when measuring the environmental benefits of CHP. The available literature, which mainly relies on US-based evidence, proposes five tests to assess cost-effectiveness of the CHP plant (Bluestein et al., 2014, Tsui et al., 2016). The general approach is that when the net present value (NPV) of future benefits is higher than the NPV of costs of the CHP plant, the investment is worth the expenditure. The Total Resource Cost (TRC) test compares the avoided supply-side costs and resource savings, e.g. reduced fuel costs and transmission and distribution costs, with the cost of installation and of administering the programme. The Societal Cost Test (SCT) additionally includes external benefits, e.g. avoided emissions[270] and related health benefits. The Ratepayer Impact Measure (RIM) measures changes for those not installing CHP: costs include the loss of revenue for utilities[271], the administrative and the incentive costs of the programme, while benefits include the lower operating costs due to, e.g., reduced fuel costs at the system level. The Participant Cost Test (PCT) assesses the costs and benefits from the perspective of those who install CHP plants: costs include the plant installation, while benefits include subsidies and reduced bills. The Program Administrator Cost Test (PACT) assesses the measure from the government point of view: costs include the incentives and the administrative costs of the programmes, while benefits include reduced peak-load hours and avoided costs for construction of power plants and distribution grids. The results of the tests can point in different directions. The literature suggests that TRC and SCT can be used to assess if a programme is cost-effective, while distributional tests (RIM, PCT, and PACT), measuring how different stakeholders are affected, can serve as guidelines to balance incentive levels, goals for adoption rates, and costs to ratepayers. A final benefit to be considered is energy resilience: CHP can provide energy during times of power-grid outages.

Finally, cost-effectiveness of energy efficiency programmes is generally assessed based on the cost of the support per MWh saved. Friedrich et al. (2009) assess the cost-effectiveness of both residential and industrial energy efficiency programmes implemented in

[270] While it is difficult to achieve consensus on the price of abated emissions, a Netherland-based study identified CHP as one of the least-cost solutions at €25/tonne CO_2. See IEA Report - 2008.
[271] Reduced energy sales can lower revenues and put upward pressure on retail rates as the remaining fixed costs are spread over fewer kWh.

nine U.S. states.[272] While the costs include the programmes administration costs and the participants' costs, the benefits are obtained by multiplying the energy savings by the appropriate avoided costs. Benefits are also net of those changes in use and demand that would have happened even in the absence of the programme (free riders).[273]

Similarly to the criterion €/tCO_2 avoided, the metrics used to assess the cost-effectiveness of CHP and energy efficiency programmes take into account both the cost per unit of energy produced and the contribution to the environmental objectives (e.g. energy saved, avoided emissions, health benefits), thereby favouring a better scrutiny of the measures to be aided.

Annex 1.1.2 Interaction of RES support and ETS

ETS has been often considered as the first best policy option: extensive literature shows that GHG pricing tends to be the most cost-effective way to reduce emissions (see for instance Palmer and Burtraw, (2005), Fischer and Newell (2008), Böhringer et al. (2009), Flues et al. (2014)). In addition, overlapping policies such as ETS and RES support are considered emission neutral: before the launching of ETS, BMWi (2004) suggests abolishing RES support, as it would result in zero emission reductions if implemented together with a cap-and-trade system; Morris (2009) and Pethig and Wittlich (2009) point out that, under an efficient ETS, zero incremental emissions reduction will be realised from a supplementary renewables quota system. This literature however discards that the cap is not static, but subject to policy reforms, and can been adjusted when there is a surplus of allowances. The cap setting is also based on impact assessment analysis, which model the EU ETS in addition to the existing RES policies, thereby creating an explicit link between the Member States' RES policies and the cap setting (Agora (2018)).

There is a strand of the literature that focuses on the interaction of these instruments and argue that they may achieve better outcomes compared to the results of each policy taken separately.

Weigt et al. (2013) find that carbon emission abatement in the power sector is higher when RES support is in place simultaneously to the ETS. Müsgens (2018) assesses that ETS prices alone would not be enough to trigger investments to reach the RES policy targets. The sequencing literature also points toward the combination of ETS with RES policies, given that direct emission pricing could face major political obstacles. RES support reduces the cost of low-carbon technologies and strengthens clean-energy industries, gradually building a broader political support for low carbon policies and paving the way for carbon pricing at later stages; nevertheless, even if politically more effective, this policy pathway may face significant challenges as excess rent capture and lock in (Meckling et al. (2015, 2017)). Leipprand et al. (2020) finds, however, that growing coalitions supporting carbon pricing theorised by Meckling et al. did not emerge for a long time, as two largely separate actor communities concerned with RES and ETS engaged in antagonistic competition.

Hirth et al. (2013) also explain that a mix of policies is advisable if large redistributions effects want to be avoided: by assessing the distributional effects of RES support and carbon pricing, the study finds that the latter transfers economic surplus from consumers to producers (i.e. producers' rents increase) while the former does the opposite. On the one hand, support policies introducing RE capacity in the market decrease the wholesale electricity price below the level it would have been otherwise: for instance, wind power has low variable costs, reducing the wholesale electricity price any time it is windy; this in

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[272] These programs are intended to provide incentives to consumers and businesses for saving energy through the purchase of energy efficient equipment and/or changing behaviours related to energy consumption.

[273] Some paper argues that energy efficiency improvements are the least costly policy interventions for environmental protection (Friedrich et al., 2009, Allcott and Mullainathan, 2010). Allcott and Mullainathan (2010) assess the cost effectiveness of an efficiency energy program aimed at reducing households' energy consumptions in the U.S. The paper finds that the costs to the utility per kWh saved is 2.5 cents and that the program could reduce CO_2 emissions from electric power by 0.5%, while actually saving $165 per metric ton of reductions. This compares very favourably with other, more traditional strategies to reduce carbon emissions; wind power, carbon capture and storage added to new coal power plants, and plug- in hybrid vehicles are estimated to cost $20, $44, and $15 per metric ton of CO_2 abated.

turn reduces the existing generators' profits and increases consumer surplus. CO_2 pricing inflate the variable costs of carbon emitting plants instead: in the case of price-setting generators, CO_2 pricing increases the electricity price, reducing in this way consumer surplus; at the same time, low-carbon plants such as nuclear and hydro power benefit from higher prices without having to pay for emissions. A combination of the two instruments would therefore ensure CO_2 emissions reduction without changing conventional generators' rents too much (Hirth et al. (2013)).

Annex 1.2 The design of industrial decarbonisation schemes, and namely CHP schemes

This annex provides further evidence on how the effectiveness of CHP schemes can be improved.

Support schemes have not always been effective in subsidising CHP investments: an analysis from Moya (2013)[274], based on data from the Cogeneration Observatory and Dissemination Europe (CODE)[275] project from 2002 to 2008, shows that support measures have not played a key role in promoting CHP. In particular, the study concludes that Members States in which cogeneration projects where subsidised have not been more effective in promoting CHP technologies than Member States where these schemes were not in place[276]. The study identifies three main barriers that have hindered the development of CHP: deficiencies of support schemes (e.g. the uncertainties provoked by the short term of the support measures), lack of expertise (e.g. the low maturity of some technologies used to process the fuel in CHP), and complexity of the law (e.g. coordination between the different administrative bodies as regards deadlines, reception and treatment of applications for authorizations). Moya (2013) also observes that, compared to RES technologies, increasing CHP is more complex, as it should be installed either in cities or industries. For example, the barriers to switching a whole city to CHP district heating are of a different order than obtaining permission for a wind farm.

The literature highlights that CHP support schemes should be differentiated based on the plant's size. The evaluation commissioned by the German Federal Ministry for Economic Affairs and Energy (BMWi) on the German CHP Act points out that there might be insufficient competition for CHP plants above 50 MW (e.g. only 4 eligible projects for year) and that tendering should be discouraged in this case. While the first three German CHP tendering rounds[277] have shown that auctions for support can also work well in the CHP sector, the adoption of tendering for CHP plants above 50 MW should be carefully designed. Separate tenders for plants above 50 MW would not be helpful: the number of tender rounds will be reduced to one every two years to achieve a sufficient number of bids and the associated long waiting time between tenders could lead to greater uncertainty for investors.

Based on data on the cogeneration's growth in the US[278], Kalam et al. (2012) finds that, in gas turbine applications above 83 MW, CHP technology is cost-competitive without financial incentives, while small-scale require funding to further develop.[279] Athawale et al. (2014) propose, instead, to differentiate the support based on the CHP plant's capacity utilisation. Through an analysis of historical data in the US, the study shows that plants' profitability largely depends on the hours of capacity utilisation, and that the probability of losses arising from lower than expected capacity utilisation could hinder investments in

[274] CHP Directive 2004/08/EC.
[275] All the EU-27 States, except from Croatia, and including the United Kingdom.
[276] In addition, the paper finds that countries with a high penetration of CHP are more sensitive to changes in support measures: specifically, results show that countries with well-developed cogeneration systems, depending on the presence of economic support, tend to see larger decreases or increases in CHP than other countries.
[277] The first tender round was in December 2017, followed by the second in June 2018 and the third in December 2018.
[278] Between 1997 and 2007.
[279] Even if outside the scope of the paper, Kalam et al. (2012) state that steam turbines are potentially cost-competitive as well, especially in small-scale applications.

new CHP projects. The paper proposes an incentive scheme based on assurance payments whereby the public agency would pay cogeneration plants' owners to mitigate demand risk for the electricity and thermal output from the CHP system. If in a particular year the plant is unable to meet the minimum breakeven capacity factor, which means the CHP operates for less than-expected hours, then the project becomes eligible for an assurance payment.[280]

Box 1 presents three CHP schemes implemented in Europe.

Box 1: CHP schemes in Europe

- Since 2007, Poland has supported CHP through a quota system whereby CHP plants are awarded different type of certificates according to their size and fuel. The system requires utilities to purchase and redeem a specific number of CHP certificates, in proportion to the amount of power supplied to end users. [281]. Between 2007 and 2014, according to a report from the Institute of Applied Research of Politechniki Warszawskiej, 62.03 Mt of CO_2 have been avoided. In 2019, the Polish quota system has been replaced by the CHP Act which envisages the use of a competitive bidding process to set the support for new and substantially refurbished CHP plants between 1 MW and 50 MW, and administratively set premiums for other type of plants. The premium is paid on top of the market price and revised once a year to adjust for inflation. The support price in the auction of December 2019 was between PLN 60/MWh and 98.13/MWh. [282]
- The Danish scheme of 2012 supports industrial gas-fired CHP plants through a uniform price supplement per kWh electricity produced. [283]
- Germany introduced the CHP Act in 2002 to promote CHP plants and, with the last revision of the law in 2016, has doubled the funding for cogeneration's support. The CHP Act also envisages the use of tenders to select the beneficiaries of a fixed premium on top of the market price. [284]

Source: Lear.

Annex 1.3 Competitive bidding as means of granting aid

This annex provides further evidence on (i) the preferred pricing rule for RES auctions; (ii) on how to implement multi-criteria auctions, also based the available literature on conservation programmes285; (iii) the trade-off between technology-neutral and technology-specific auctions, and (iv) the extension of competitive bidding to allocate funds for energy efficiency measures. As mentioned in section 1.2.3, the general findings on the impact of the design of competitive bidding procedures on competition and cost discovery are applicable to any auction scheme, although the reviewed literature is mainly based on RES and energy efficiency programmes.

Annex 1.3.1 Preferred pricing rule for RES auctions

The AURES II project provides a database[286] collecting RES auctions formats and results between 2011 and beginning of 2020. According to the database, the preferred pricing

[280] The idea here is to make up for the losses incurred as a result of reduced operations, which might have occurred as a result of macroeconomic conditions beyond the owner's control. Athawale et al. (2014) also stress that with the assurance-based incentive structure, however, there is a possibility that for projects demonstrating better capacity factors, the public agency would end up providing lower incentive payments to owners than it would have otherwise paid. Ideally projects that can sustain high capacity factors should be encouraged, and the assurance payment system requires an ex-ante screening of plants with high capacity factors.
[281] SA.36518 Certificates of origin for CHP in Poland
[282] See URE. SA.51192 CHP support.
[283] SA.35486 Aid for electricity generation in industrial combined heat and power plants
[284] SA.42393 Reform of support for cogeneration in Germany.
[285] Conservation programmes are programmes designed to encourage agricultural producers and landowners to undertake conservation practices on agricultural lands, i.e., for the conservation of soil, water, vegetation and other applicable natural resources for an area of land.
[286] *Database - AURES II (aures2project.eu)*

rule in Europe during the last decade has been the pay-as-bid rule, with less than 10% of auctions using a pay-as-clear rule[287].

Table 18: Pricing rule of RES auctions

Pricing rule	Frequencies	Percentage
Pay-as-bid	164	90.1
Pay-as-clear	18	9.89%
Total	182	100%

Source: Lear based on AURES II database.

Annex 1.3.2 Multi-criteria auctions

Ausubel et al. (2011c), propose three main formats for multi-criteria auctions for offshore wind projects in the U.S: the single-phase, the two-phases multifactor auction (MFA) and the scoring approach. In the single-phase MFA bidders submit a sealed bid containing both a technical and a commercial proposal, which can be considered either sequentially (first the technical proposal is evaluated to determine if minimum standards are met, then the commercial proposals are evaluated for those bidders' whose technical proposal qualified), or together. In a two-phases MFA, after the technical phase is evaluated, bidders will know if they are awarded any preferential treatment such as discounted bids and can revise their commercial proposal accordingly. If the second phase is implemented as an auction to reveal information about other bids (e.g. a clock auction with bids disclosure), it will allow bidders to compete more efficiently. A scoring auction allows each bidder to bid multiple factors, which are then aggregated into a score. The bidder with the highest score wins. Since price is only one of the factors that enter the score, bidders have the incentive to choose the technical characteristics of their bid to maximize their technical score and adjust their financial bid accordingly. This leads to efficient outcomes only if the technical portion of the scoring rule accurately reflect the trade-offs inherent in the service being provided.

The literature on conservation programmes provides further evidence on how to implement multi-criteria auctions. Some examples are the CRP (Conservation Reserve Program) in the USA and the BushTender in Australia (Latacz-Lohmann et al.; 2005). Claassen et al. (2008) and Connor et al. (2008) report that the use of an Environmental Benefit Index ("EBI")[288] to prioritise the bids proved to be effective in conservation and agri-enviromental payment programme. Connor et al. (2008) further compares the auction results to four subsidy schemes: a uniform payment in which a project is selected if its costs are lower than those of a prior payment programme, until budget exhaustion; a negotiated payment in which the subsidy is the outcome of a bilateral negotiation between the agency and landholders, with projects selected until budget exhaustion; a uniform payment with project select based on the value of environmental benefit (EB/$), and a negotiated payment with projects selected also based on the value of the environmental benefit. Table 19 reports the results of the simulation: using the EBI to select projects, and then privately negotiate the payments with the landholders, can be more cost-effective than auctions, i.e. it leads to the same environmental benefits of an auction with a lower level of expenditure. This implies that the efficiency gains of the conservation programmes resulted from

[287] Note, however, that the databse classifies the UK CfD auctions as pay-as-bid, rather than pay-as-clear, as participants bids for amounts and year of delivery, hence the same auction will yield different prices, as the uniform pricing is applied only to projects with the same delivery year. If corrected to consider the UK auctions as a pay-as-clear, this would increase the percentage of pay-as-clear auctions to 12.09%.

[288] Defined by Claassen et al. (2008) as "a benefit–cost index that accounts for a broad range of environmental concerns and the cost of the contract to the government". Points are assigned to different categories such as wildlife benefits (up to 100 points), water quality (up to 100 points), soil erosion (up to 100 points), enduring benefits (up to 50 points), and low costs (variable). See USDA-FSA 2003

the prioritisation of projects through the EBI, rather than from the cost discovery intrinsic to the competitive bidding process.

Table 19: Connor et al. (2008)'s policies comparison

Policy	Cost ($) of achieving the auction level of environmental benefits	Level of EB (millions) achievable with auction level of expenditure	Percent of auction environmental benefit attained at the auction expenditure level
Discriminative auction	139,278	20.9	
Uniform payment	n/a	11.7	56%
Negotiated payment	n/a	14.3	68%
Uniform payment with EB/$	209,307	19.9	95%
Negotiate payment with EB/$	118,45	21.4	102%

Source: Connor et al. (2008).

Annex 1.3.3 Technology-neutral and -specific auctions for RES

In 2014, while Germany was revising the EEG and evaluating to include competitive bidding procedure to allocate renewable energy support, there were many exponents arguing in favour of technology-neutral tenders.

Jägemann (2014) argued that support should be awarded based on the net marginal cost (the difference between marginal cost and marginal value of the energy produced), which increases with the level of technology penetration, rather than the marginal costs. Technology-neutral schemes allow to award a mix of technologies with equal net marginal costs and so a lower level of subsidy, while a technology-specific auction would select the technology with the lowest marginal cost, which is not necessarily the efficient choice.[289] Frontier (2014) claimed that technology-neutrality renders the achievement of volume objectives easier, leading to a greater expansion of RES.

As also discussed in section 1.2.3, those arguing in favour of technology-specific tenders claim that the latter promote technology diversity, while technology-neutral tenders may not be able to minimise costs in the long run. For this reason, subsidy measure should discriminate across technologies with different costs. This is indeed what has been recently proposed for a scheme in the UK.

The UK Department for Business, Energy & Industrial Strategy (BEIS) is currently revising the UK scheme to support renewable energy generation technologies[290], which is based on contracts for differences (CfD), to support technologies' diversity (BEIS, 2020). CfDs are a variable premium, computed as the difference between a "strike" price and the market price, and are awarded through a competitive bidding process. Different technologies compete against each other within groups or "pots". There are two pots, namely the Established (Pot 1) and Less Established (Pot 2):[291] BEIS (2020) proposes to move offshore wind from Pot 2 to a separate pot, given its differences in terms of development timeline, size of projects and expected costs, and to define a separate technology with its own strike

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[289] Jägemann (2014) estimates the extra cost for Germany to be around €6.6bn.
[290] SA.36196 Contract for Difference for renewables in UK.
[291] The pot for established technologies includes onshore wind (>5MW), solar photovoltaic (PV) (>5MW), energy from waste with combined heat and power (CHP), hydro (>5MW and <50MW), coal-to-biomass conversion, landfill gas and sewage gas. Less established technologies are offshore wind, remote island wind (>5MW), wave, tidal stream, advanced conversion technologies (ACTs), anaerobic digestion (AD) (>5MW), dedicated biomass with CHP and geothermal.

price for floating offshore wind[292] in Pot 2.[293] Under this scenario, BEIS (2020) expects floating offshore wind to be able to bid at a lower price and being competitive with other less established technologies. According to BEIS 2020, this could change Pot 2 capacity mix, given that floating offshore wind could replace some of the more expensive technologies such as remote island wind and ACTs[294], and lead to a reduction of generation costs and GHG emissions valued up to £270mln between 2025 and 2050.[295]

Annex 1.3.4 Extending competitive bidding to energy efficiency programmes

Regarding the extension of competitive bidding to energy efficiency programmes (EEP), international experiences is limited but results are promising. Among the countries that have used auctions for EEP there are Portugal, Switzerland, Germany, and the United States.

Radgen et al. (2016) analyse the ProKilowatt programme in Switzerland: it is a sealed bid auction with a pay-as-bid pricing rule, where bids are ranked according to their estimated cost-effectiveness (expresses as €/MWh avoided by the measure) and are paid up to 40% of the value of the investment.296 Bids are differentiated according to two categories, projects (measures directly submitted by the owner of an installation) and programmes (measures implemented for a bundle of different owners of installations through the support of an intermediary). To ensure the "scarcity requirement", which is the main driver of cost-discovery, the bids must be at least 120% of the available budget, otherwise this will be reduced accordingly. Over the years, there has been a reduction in the range of funding for winning projects. Apolinario et al. (2012) and Sousa et al. (2018) study the PPEC programme in Portugal: this is structured as a sealed bid multi-criteria auction297 (based on a cost-benefit analysis), with a pay-as-bid pricing rule. Bids are differentiated between tangible and intangible measures (the latter being behavioural programmes), and by sector (industry and agriculture, commerce and services, and households). Since the second edition a maximum of 80% of a project's costs can be funded by PPEC (the remaining must be funded by project sponsors), but results have exceeded expectations: in 2017 only about 50% of the value of the winning projects was funded by PPEC, implying a leverage effect of €1 of investment for each €1 of aid, and a strong reduction of the support level. Based on the Swiss experience, Germany launched STEP up! in May 2016. Auctions follow a pay-as-bid pricing rule but pay back up to 30% of the extra investment costs necessary to achieve a higher energy efficiency level.298 Bids are ranked based on their cost-effectiveness (€ of funding per saved kWh). Auctions are also differentiated

[292] A unit which generates electricity by the use of wind and which is a) situated in offshore waters exceeding 60 meters depth, and b) is a floating structure. In these deeper water sites fixed bottom offshore wind is either unfeasible or uneconomic.

[293] According to the study, floating offshore wind is more costly and less developed than fixed-bottom offshore wind.

[294] Remote islands are wind farms built on island away from the UK mainland. ACTs are Advanced Conversion Technologies, used to recover energy from waste.

[295] Further revisions proposed by BEIS (2020) are the suspension of the premium at any hour with negative electricity prices, to expose producers to market signals; the extension of the Non-Delivery Disincentive period (NDD) which excludes any project that does not deliver from bidding into future rounds, and an extension of the Milestone Delivery Date (MDD) which is the date by which a project must demonstrate that a certain amount of investment has been made.

[296] Until 2015 the eligible costs to be covered by the ProKilowatt programme were only the extra cost of the investment (i.e. those that would not have been made without the programme). Since 2015, all the investment's costs are eligible, but the funding ratio is cut back depending on the age of the equipment the project would replace up to a minimum of 15%.

[297] Some of the criteria are: the weight of new equipment over total costs (to award measures that maximize investment over administrative expenses), equity (measures should not discriminate among final consumers, based on their geographical location, and their offer must be as comprehensive as possible), previous experience with similar programmes. Criteria are set before the auction, and a questionnaire and a matrix with scores for each possible criterion are available. Furthermore, the evaluation is carried first by ERSE (the Portuguese Energy Service Authority) and then by the Directorate-General for Energy and Geology

[298] As opposed to ProKilowatt, STEP up! falls under EU state aid regulation, which set the 30% threshold (art. 38 GBER).

according to two project categories, i.e. individual and composite projects ("collection projects"), and two different types of tenders, i.e. open and closed. In the first case, the applicant implements efficiency measures within his company; in collection projects, the applicant initiates and coordinates the implementation of several similar efficiency measures in different companies (i.e. the applicant acts as projects coordinator). In addition, the open tenders are open to all types of technologies and sectors, for individual as well as collection projects. The closed tender, on the other hand, focus each round on specific sectors or technologies with known high potentials and constraints and the eligibility for funding is limited to those technologies or sectors (e.g. modernisation of elevator systems, heat and power savings).299 Even though the pilot phase of STEP up! has not met the expectations, the introduction of competitive bidding processes has been considered a success (Ifeu and Prognos (2019)). Finally, the USA case is different, as energy efficiency can participate in the capacity market of New England and some mid-Atlantic and Midwestern states (Neme et al., 2014). Both capacity markets are structured as a descending clock auction, with a uniform pricing rule and use prequalification criteria and bid bonds. It is estimated that in the first auction, the presence of energy efficiency measures reduced the clearing price and led to savings between $290 and $430 million.

For most of the EEP auctions, benefits have been higher than expected: ProKilowatt in 2014 saved around 700 GWh, using a budget of €20 mln, with a mean cost-effectiveness of 30€/MWh avoided; PPEC in 2007 avoided 770 GWh of electricity (against an ex-ante estimate of 390 GWh), and helped reduced CO_2 emissions by 285.000 tonnes; in New England energy savings during peak hours were more than 120% of the amount bid. During its pilot phase from 2016 to 2019, STEP up! has instead saved around 113 GWh with a mean cost-effectiveness of 28€/MWh avoided. Overall, international experience shows that the use of competitive bidding in EEP, for both industrial processes and investments in the private sector, has been successful, with high levels of participation in the auctions and results exceeding expectations.

Annex 1.4 Multi-sector/multi-technology schemes for decarbonisation

This annex provides further evidence on the multi-technology and multi-sector schemes analysed in section 1.2.4, and specifically: (i) the eligible technologies of the programmes analysed in section 1.2.4; (ii) the functioning of the Dutch SDE+; (iii) the measurement of cost-effectiveness of the Swedish *Klimatklivet*; and (iv) a summary of the findings on multi-sector and multi-technology schemes.

Annex 1.4.1 Eligible technologies and functioning

Table 20 lists all the technologies eligible for support according to each of the multi-technology and multi-sector subsidy programmes reviewed.

[299] See Langreder et al. (2019).

Table 20: Eligible technologies in multi-technology and multi-sector programmes

Programme	Eligible technologies
EIA	Energy saving and renewable energy technologies, depending on the yearly Energy List (e.g. in 2020 it was divided into seven eligible categories: commercial buildings, processes, means of transport, renewable energy, energy balancing, energy transition and energy recommendations)
Energy Efficiency Fund	Energy efficiency measures targeted at various actors, such as industries, private consumers, and municipalities.
Klimatklivet	Biogas, energy conversion measures, renewable district heating, biofuel, energy efficiency measures, chargers for electric vehicles, waste facilities, cycle route management
MAP	Support is granted to: i. solar thermal energy, biomass and heat pumps for plants with capacity up to 100 kW by the Federal Office of Economics and Export Control (BAFA) in the form of investment subsidy; ii. large solar thermal plants, biomass heating plants, certain efficient heat pumps, biogas pipelines, deep geothermal plants, local heating networks for heat from renewable energies (subordinate to KWKG support) and large heat storage facilities for heat from renewable energies by Credit Institute for Reconstruction (KfW) in the form of low-interest loan.
RES-E tenders - Denmark	Offshore and nearshore wind, solar
RES-E tenders - France	Onshore wind, solar, biomass, hydro
RES-E tenders - Germany	Offshore and onshore wind, solar PV, biomass
RES-E TGC - Sweden	Wind, solar, biomass, CHP geothermal, wave
SDE+	Offshore and onshore wind, solar PV, solar thermal, biomass, hydro, geothermal
SDE++	Wind, solar, hydro, osmosis, geothermal, biomass, composing mushroom compost, solar and aqua thermal, electric boiler, heat pump, electric boiler, waste heat, hydrogen through electrolysis, CCS
STEP up!	All technologies improving electrical energy efficiency, including *inter alia* projects for combined heat and power, efficiency measures within the framework of contracting and energetic refurbishment of lift systems.

Source: Lear.

Box 2 also describes the key characteristics of SDE+, a multi-technology subsidy programme introduced in the Netherlands in 2011.

Box 2: The functioning of SDE+

SDE+ was set up in the Netherlands in 2011 with the goal of encouraging the production of energy from RES and of generating it at the lowest cost possible. SDE+ is an operating grant and provides support in the form of a sliding feed-in premium (FIP), calculated on a yearly basis by the difference between the bid price (i.e. base amount) and the correction amount. The correction amount is calculated annually based on actual market prices and is the average price of energy per technology, where the base energy price is the lower bound of the correction amount. The FIP is determined through multi phase technology-neutral auctions, as all technologies compete under one budget ceiling split in allocation rounds. The exception is offshore wind, which is auctioned under a separate budget through a process which also allocates the operating concessions for the seabed. According to AURES II (2019) on Dutch auctions, offshore wind auctions allow zero subsidy bids since 2017 and are evaluated on the basis of the following criteria: i) knowledge and experience of the parties involved; ii) quality of the design for the wind farm; iii) the capacity of the wind farm; iv) social costs; v) quality of the inventory and analysis of the risks; vi) the quality of measures to ensure cost efficiency.

Bids are bound by technology-specific ceiling prices and phase specific ceiling prices, with phase ceiling prices rising in each subsequent phase. While the technology-specific ceiling prices minimize windfall profits (especially for the least expensive technologies), the phase ceiling prices ensure that expensive technologies compete with cheaper technologies only by bidding below the phase ceiling price, thereby avoiding an upward pressure on the bids. The existence of a disclosed ceiling may however lead participants to bid close to the ceiling. Depending on the combination between the technology ceiling and the phase ceiling determines, project developers can bid for the technology-specific ceiling price or are bound by the phase specific ceiling price (AURES II (2019)).

Thus, as opposed to its predecessor SDE, the SDE+ no longer has separate budget ceilings for each technique and introduces on the other hand the free category. The free category provides developers of more expensive technologies with the opportunity to access the SDE+ sooner and thus increase their chance to receive support. According to AURES (2019), the free category was especially relevant in the early years of SDE+, when more expensive technologies were only able to participate in the early phases through it, as they were not provided with their own category in early phases. According to the International Energy Agency's (IEA) description of SDE+ in its policies database, the "free category" intends to drive cost-reduction among the more expensive technology brackets and promote "technology leaders" with a more efficient cost-model.

In 2020 the Netherlands introduced the SDE++, which is an evolution of the SDE+ involving additional technologies and scoring projects on the basis of €/tCO_2 reduced rather than EUR per unit of energy output.

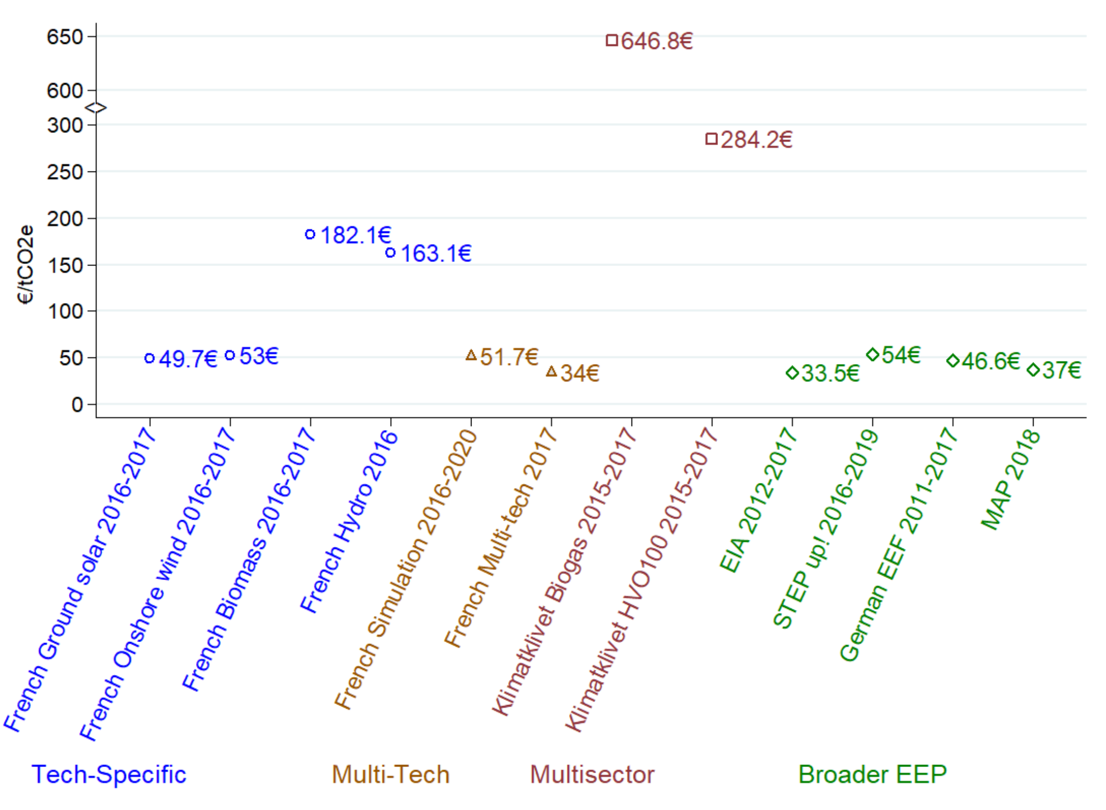
Source: Lear

Annex 1.4.2 Cost-effectiveness of multi-technology and multi-sector schemes

Figure 30 and Figure 31 show the estimates of the cost-effectiveness provided by the studies reviewed in section 1.2.4. While Figure 30 represents the available estimates in terms of € per tonne of abated CO_2 equivalent[300], Figure 31 shows the available estimates in terms of € per MWh produced or saved. Each figure presents at least one scheme for each of the categories identified (multi-technology and technology-neutral schemes for RES-E support, multi-sector schemes, broad energy efficiency programmes).

[300] Note that the French estimates are not in €/tCO_2e but in €/tCO_2.

Figure 30: Cost-effectiveness of multi-technology and multi-sector schemes[301]



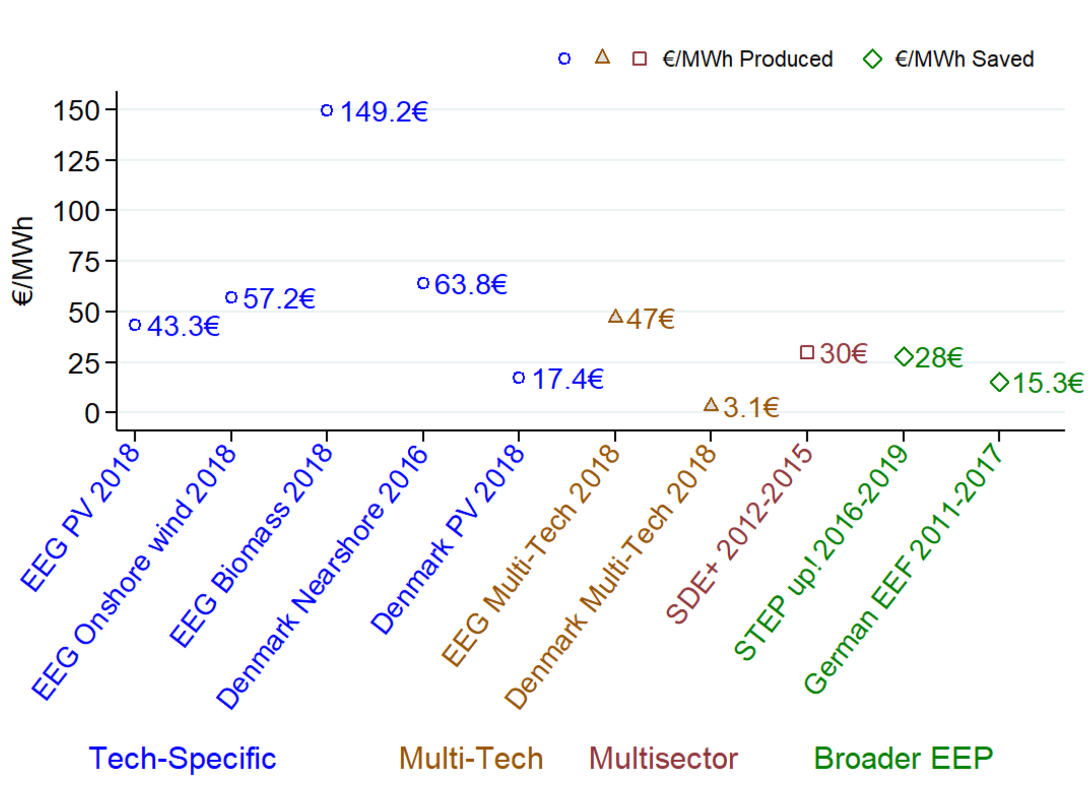
Source: Lear.

Figure 30 shows that, while the Dutch and German energy efficiency programmes (EIA, Step up!, MAP and EEF) are, on average, more cost-effective, the Swedish multisector scheme shows quite high cost values. It is worth mentioning, however, that EIA estimates are corrected to consider the presence of free riders and the Swedish estimates are those provided by Riskrevisionen (2019), after correcting to account for double-counted CO_2 emissions avoided, indirect and not realized emission reductions and the interaction with other policy instruments. The simulation results of the French technology-neutral are in line with those of the most effective technology-specific tenders, i.e. wind and solar.

Figure 31 shows instead that the German energy efficiency programmes (STEP up! and Energy Efficiency Fund) are, on average, more cost-effective than the Dutch multisector programme (SDE+). The German multi-technology/technology-specific auctions (EEG 2018) are on average less cost-effective than the Danish ones, especially the multi-technology. EEG Biomass auctions are the least cost-effective in terms of €/MWh produced.

[301] Figures provided for Klimatklivet HVO100, EIA and German EEF are simple averages based on the following values: Klimatklivet HVO100 235.2-333.2€/tCO_2e; EIA 21-46€/tCO_2e; and German EEF 2.2-90.9€/tCO_2e.

Figure 31: Cost-effectiveness of multi-technology and multi-sector schemes[302]



Source: Lear.

Box 3 discusses the challenges encountered when assessing cost-effectiveness of the projects eligible for *Klimatklivet*. Although it covers some cases not covered by the GBER, it might provide some useful insights on how to assess cost-effectiveness for broader schemes.

Box 3: The cost-effectiveness measurement of Klimatklivet

Klimatklivet is a comprehensive environmental initiative introduced in 2015 in Sweden to support local climate investment. Eligible measures are prioritized based on the amount of emission reductions they are expected to generate per invested Swedish krona. Recently, the Swedish National Audit Office has reviewed the aid programme to assess, *inter alia,* whether it contributed to achieve Sweden's climate goals in a cost-effective way. The review has identified three main flaws of the methodology implemented to measure cost-effectiveness:

- the expected emission reductions are not properly assessed. First, the review points out that in those cases in which a chain of measures is needed in order to abate CO_2 emissions, the reduction is double counted. For instance, to achieve the conversion from fossil fuels to biogas in the transport sector, the biogas must be produced, distributed (e.g. gas station) and used (e.g. in a biogas bus). Each stage can be supported within *Klimatklivet* but they lead to the same emission reduction. Second, *Klimatklivet* also supports measures that reduce emissions indirectly, like the constructions of cycle paths and cycle garages. These cases of indirect reductions pose not only the risk, that the same climate benefit is counted several times, but also that the reduction in emissions is not realised at all. For instance, the cycle paths and cycle garages might not be attractive

[302] Figures provided for SDE+ and German EEF are simple averages based on the following values: SDE+ 27-33€/MWh; German EEF 0.9-29.7€/MWh.

enough to convince citizens using cars with combustion engines to switch to a bicycle, e-bike.

- the interaction with other climate-related economic instruments, such as the carbon tax or the bonus malus system[303], is not properly taken into account: the review points out the emission reductions are overestimated as, in some cases, the reduction is not attributable to *Klimatklivet* but to other environmental protection schemes in place. A survey conducted by the Swedish National Audit Office points out that just over half of the measures that have granted support are additional, i.e. they would have not occurred if *Klimatklivet* had not been introduced. Other measures would have been implemented in smaller or in full scale even without support.
- the cost-effectiveness should be measured on the basis of the socio-economic costs resulting from a measure to reduce emissions. As per the 2014 EEAG, the aid should be equal to the extra-investment costs, compared to the alternative technology that would have been deployed without the aid, e.g. the fossil fuel plant. Sometimes, it is difficult to identify the alternative, e.g. for the charging stations, and the extra-investment cost end up being equal to the entire investment cost. Even in these cases, however, the scheme's cost-effectiveness should be assessed on the basis of the socio-economic costs of the supported measures, i.e. the investment costs net of the expected revenues that the measure will generate, also in related sectors (e.g. investment in a fast-charging stations can feed the business of e-mobility services, and generates additional revenues which can cover the cost of the investment). This amounts to the government costs of the measure, i.e. the support. The Swedish National Audit Office points out that cost-effectiveness should be calculated on the basis of the quota of emission reductions per *granted* krona, rather than the currently applied quota of emission per *invested* krona.

Source: Lear.

Annex 2 Case studies conceptual framework and methodology

Annex 2.1 Extended conceptual framework description

The determination of mitigated CO_2 emissions principally requires a counterfactual to be defined. We assume here that the counterfactual is the absence of the investigated part of the selected support schemes, including operational, as well as investment impacts in the electricity sector, as well as other coupled sectors (both effects will be discussed in more detail later). Furthermore, we assume that the system is on a pathway towards climate neutrality. As will be discussed later, while the analysis of marginal impacts of CO_2 prices and emission factors is similar to a carbon mitigation analysis, there are significant differences.

We assume the overall impact of the analysed support schemes on the overall energy system and markets to be marginal. This allows us to simplify the analysis to the marginal impact of the respective policy in question. The reason is that otherwise the definition of the counterfactual becomes highly dependent on a strong set of assumptions, for example how the EU energy system would have developed in the absence of renewable policy schemes in the last 20 years. However, it should be noted that some support schemes under investigation are significant enough to have non-marginal impacts.

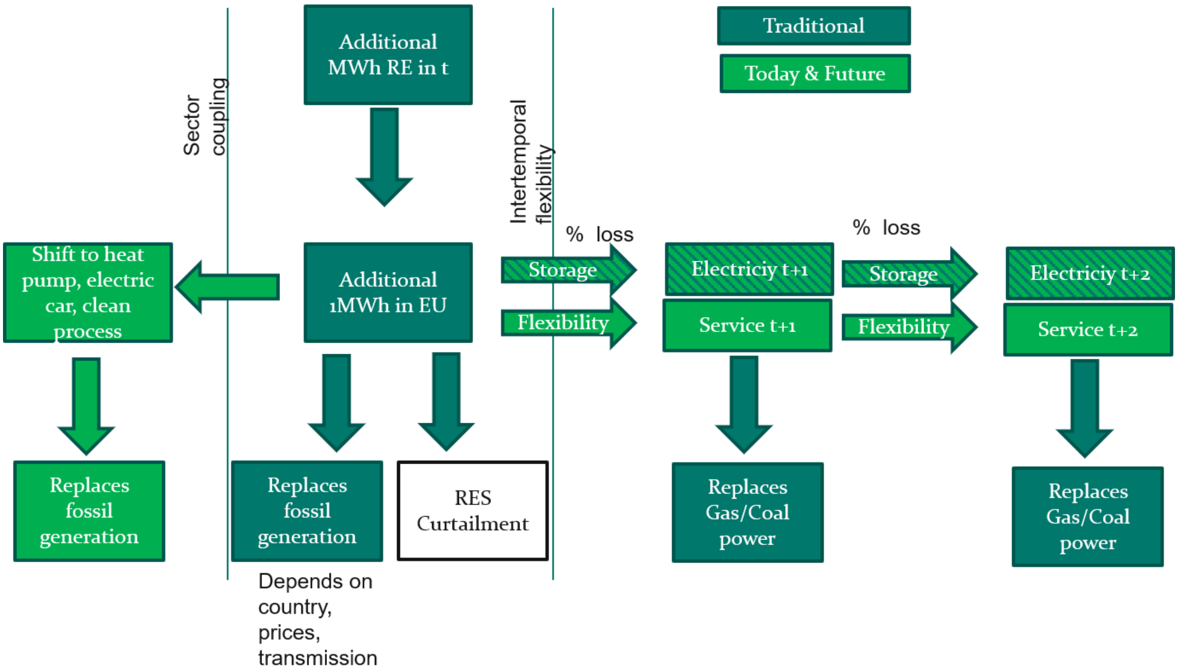
The second key assumption is that the marginal effect on price changes of the EU ETS, which overlaps with the sectors under investigation, in the counterfactual is disregarded. The reason for this is that the magnitude of a waterbed effect is highly difficult to estimate, and may be quite low, as the EU ETS is not a static policy set for decades, but dynamically impacted by policy processes, such as regular review process and the MSR reform. These

[303] This system, introduced by the Swedish government in 2018, entails a bonus for vehicles (i.e. private cars class I and II, light busses, lorries) with low CO_2 emissions (i.e. up to 60g/km) and an increase of the vehicle tax for three years for vehicles that emit large amount of CO_2 (see https://www.transportstyrelsen.se/en/road/Vehicles/bonus-malus/).

are in turn informed by price and quantity developments within the EU ETS. We therefore assume the waterbed effect to be zero within our calculation and instead propose to correct for the existence of the EU ETS on the cost side of the indicator, by adding a ETS price component to the costs, that aims to indicate what support would be needed in the absence of emissions prices (Section 1.2.1).

In the following we will conceptually discuss carbon mitigation effects in the current and future power sector of three different technologies. Figure 32 illustrates these effects for the case of renewable technologies, which will be discussed in more detail.

Figure 32: Marginal carbon mitigation impacts of renewable energy schemes in the power sector & coupled sectors



Source: DIW Berlin.

In case of renewable technologies there are several carbon displacement channels (and a situation of no displacement).

- **Direct replacement:** The first channel is via the direct displacement of production from fossil fuel sources, in hours in which these are marginal according to the hourly profile of the renewable technology and adjusted for storage effects. This is the case up to high shares of renewable or nuclear energy, as these, due to their lower variable costs, precede the conventional sources in the merit order.
- **Replacement in adjacent hours:** Nonetheless at high shares of renewable technologies, prospectively reached in the 2030s, non-emitting technologies (storage and flexible demand, and renewables in case of curtailment) become the price setting marginal technologies for a significant share of the year. Additional renewable power generation in such hours will trigger additional storage or flexible use of sector coupling technologies (e.g. EVs, electrolysers and bivalent processes). Storage is then discharged, or flexible demand replaced in the expensive hours of the year where conventional technologies are still producing and emitting.
- **Curtailment of renewable technologies:** However, as it is not cost-optimal to completely avoid the system-wide, as well as grid-related curtailment of renewable energy (i.e. install sufficient storage or flexibility options to use the yearly renewable production peak), both short- and long-term analysis show that a certain level of curtailment occurs. This level tends to be smaller with more ambitious carbon mitigation scenarios, as the energy is used in sector coupling (cf. Victoria et al., 2019; Bernath et al., 2021). Additional production of electricity in already curtailed time periods will not replace any generation, and hence does not lead to mitigation of

carbon emissions. The optimal curtailment levels may also be different for different technologies.

Box 4: Sector coupling

Electrification of other sectors is seen as an economic means to decarbonise further sectors such as heating, transport, and industry. This raises the question of how emission reductions should be allocated between the power sector and the use sector, and of how the cost-effectiveness of support schemes should be calculated.

In the case of a fully decarbonised electricity system and if sector coupling technologies (e.g., battery electric vehicles) have no incremental costs as compared to conventional technologies (e.g., conventional cars), all emission mitigation could be attributed to the power sector in the evaluation of the cost-effectiveness of support mechanisms for renewables.

However, for the timespan investigated, a fully decarbonised system is not analysed. Thus, we assume instead that if sector coupling technologies have incremental costs then some of the emission mitigation will likely need to be attributed to the evaluation of cost-effectiveness of electrification. For the purpose of this study we propose a common benchmark to determine the allocation of emission savings between power and use sectors. We assume therefore that, in the absence of additional renewable investment, additional electricity demand from electrification would be met via extension of operation and investment according to the conventional capacity mix. This implies, that as long as additional power is needed for sector coupling any additional renewable power generation avoids the emissions associated with generating the same amount of power through the remaining fossil power mix.

Source: DIW Berlin.

While in a short-term perspective, storage capacities are constrained, in the longer-term perspective, additional renewable generation will result in an extended period and spread between hours with low- and with higher prices. This in turn triggers – in equilibrium – additional storage and flexibility investment. Studies on systems with high shares of renewable (cf. Brown et al., 2019) show that an increasing share of renewables (and lower emissions levels) are accompanied by investments in storage and sector coupling technologies.

In equilibrium we will therefore observe that with increasing renewable penetration, the market value of renewables is gradually declining. This reflects the increased number of hours of low-prices and spread towards high prices – necessary to remunerate the increasing capacity of storage or flexibility provided to the system. However, this does not necessarily imply, that the carbon mitigation per extra unit of renewable generation is declining in parallel. To the contrary, as long as sufficient storage and flexibility potential exists or is added in equilibrium, the carbon mitigation per MWh of additional renewable electricity remains at the same level.

Annex 2.2 Detailed applied methodology

Calculation of cost-effectiveness:

The cost-effectiveness of the support for an installation i is given by the sum of discounted effective support over the support duration divided by the net mitigated emissions achieved over the lifetime or support duration of the plant:

$$Cost\ Effectiveness_i = \sum_t \frac{EffectiveSupport_{i,t} * \frac{1}{(1+\delta)^t}}{Net\ Mitigated\ CO2\ Emissions_{i,t}}$$

Calculation of effective support:

For each installation i and year t over the assumed lifetime or support duration, we first derive the expected electricity (heat) generation based on the electric (thermal) capacity of the installation and technology- and country-specific estimates of average full load hours (constant for each year of full operation; analogously for heat, and scaled down if installations were (de-)commissioned within a year)[304]:

$$Production_{i,t,electr} = Capacity_{i,electric} * FullLoadHours_{i,t}$$

Emission factors of fossil electricity (heat) generation are calculated as follows (analogously for heat):

$$EmissionFactor_{electr,t} = \frac{EmissionsFromFossilElectricityGeneration_t}{GrossFossilElectricityGeneration_t}$$

These variables are subsequently used as input to calculate support paid and net mitigated emissions.

The effective support is comprised of the payments above market values (i.e., the aid granted) and the ETS price component in each year t.

$$EffectiveSupport_{i,t} = PaymentsAboveMarketValues_{i,t} + ETSPriceComponent_{i,t}$$

The calculation of payments above market values depends on the support mechanism of the considered scheme. In the case of fixed premia, the aid is independent of market values and equal to the electricity generation times the level of the fixed premium. In the case of (one-sided) sliding premia, the aid granted per MWh of electricity generated is either i) given by the difference between the awarded level of the sliding premium and the average market value of the respective technology and year, or ii) zero if the market value exceeds the level of the sliding premium. In the case of Contracts for Difference (two-sided sliding premia), the aid per MWh electricity is equal to the difference of the awarded strike price and the average market value of the respective technology and year, with payments becoming negative (revenue to the state) when the market value exceeds the strike price.

Payments above market values for fixed premia[305]:

$$PaymentsAboveMarketValues_{i,t} = Production_{i,t,electricity} * FixedPremium_i$$

Payments above market values for sliding premia:

$$\begin{aligned} &PaymentsAboveMarketValues_{i,t} \\ &= Production_{i,t,electricity} * \max\left(\left(SlidingPremium_i - MarketValue_{t,tech}\right), 0\right) \end{aligned}$$

Payments above market values for CfDs:

$$PaymentsAboveMarketValues_{i,t} = Production_{i,t,electricity} * (StrikePrice_t - MarketValue_{t,tech})$$

The effective support granted to an installation through the electricity price component is calculated as the production times the estimate of average absolute CO2 cost pass-through (in €/MWh) to the electricity price as explained in section 1.3.1.2, as this pass-through effectively increases the revenue of the considered RES or CHP installation.

$$ETSPriceComponent_{i,t} = Production_{i,t} * \underbrace{CO2Price_t * EmissionFactor_{electr,t} * (1 - SMNE_t)}_{Esimate\ of\ average\ CO2\ price\ component\ in\ the\ electricity\ price}$$

[304] For energy efficiency measures, electricity *savings* per year are given in the data sources. In the Polish auctions, the tendered product was electricity (MWh) and results were published as MWh awarded per year (i.e. generation in 2021, 2022, …). In this case, we directly used these figures as projection of the electricity generation of supported installations.

[305] In case support is not paid in hours of negative electricity prices (curtailment), the support needs to be corrected for the curtailment rate (i.e. multiplied with (1-curtailment)). This is done for the support granted in the Danish multi-technology auctions. For the other schemes, the support is either 1) also paid in hours of negative electricity prices, 2) only not paid if electricity prices were negative in the 6 previous hours (German RES scheme), in which case a share of hours in which this is the case is lower and difficult to determine, or 3) the correction would not have much of an impact. The latter is the case for the German CHP and Danish offshore wind schemes, where the support duration is dependent on the full load hours in which support was paid (hence correcting for curtailment would slightly decrease support per year, but not affect the total full load hours supported and support paid).

Calculation of net mitigated emissions:

Net mitigated emissions are given by the sum of mitigated emissions in the electricity and heat sector minus the generated emissions (the latter two only applicable for CHPs):

$$NetMitigatedEmissions_{i,t} = MitigatedEmissions_{i,t,electr} + MitigatedEmissions_{i,t,heat} - GeneratedEmissions_{i,t}$$

As explained in section 1.3.1.1, we assume that each MWh of electricity generated displaces the average emissions of the fossil generation mix, except in the hours of curtailment of renewables. Thus, mitigated emissions of an installation in a given year t are equal to the production of electricity times the emission factor of fossil electricity generation corrected for the curtailment rate of the respective technology (analogously for energy efficiency with electricity savings instead of production):

$$MitigatedEmissions_{i,t,electr} = Production_{i,t,electr} * EmissionFactor_{electr,t} * (1 - Curtailment_{t,tech})$$

For supported CHPs, mitigated emissions from generated heat displacing (other) fossil heat generation are calculated similarly (assuming no displacement of renewable heat generation takes place in the reference scenario):

$$MitigatedEmissions_{i,t,heat} = Production_{i,t,heat} * EmissionFactor_{heat,t}$$

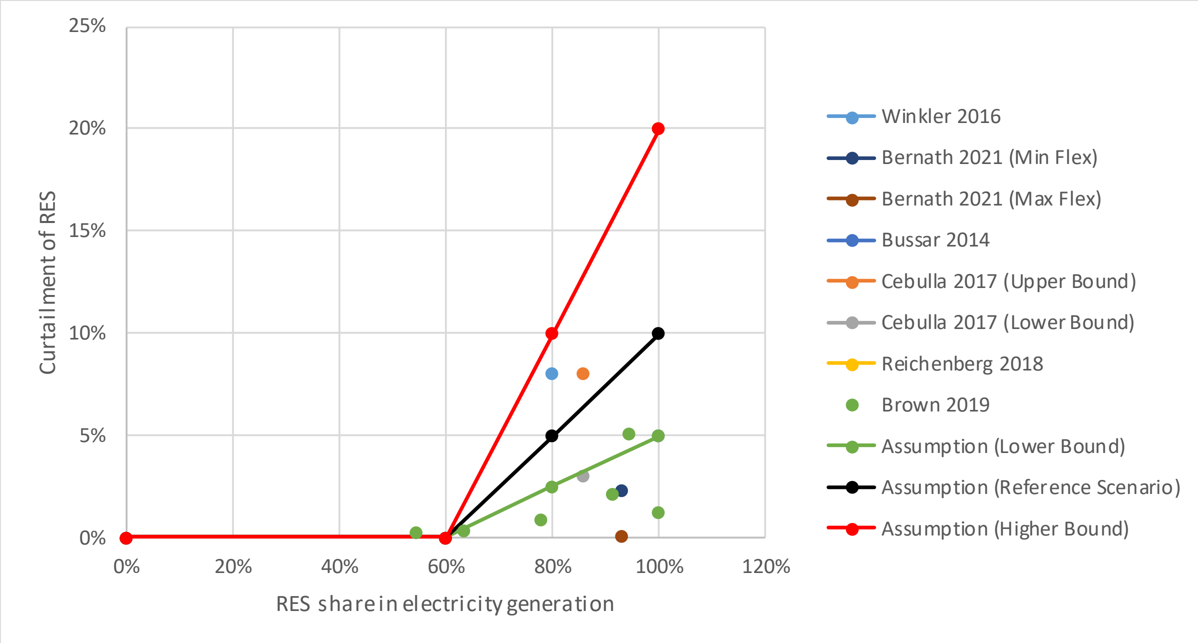
Finally, generated emissions from fossil-fuelled CHPs are calculated as follows. Primary energy (fuel) input is estimated by dividing the sum of electricity and heat generation (output) by the assumed overall efficiency of the plant (see Annex 2.3 for assumption). Emissions are then given by multiplying this result with the emission factor (tCO2/MWh) of the respective fuel.

$$GeneratedEmissions_{i,t} = (Production_{i,t,heat} + Production_{i,t,electr})/Efficiency_i * EmissionFactor_{fuel}$$

Curtailment rates are based on a literature review of mid- to long-term energy models, which typically report the share of renewable electricity generation that is curtailed in a specific (or range of) scenario(s). Figure 33 shows reported curtailment rates in the different scenarios and/or sources and the share of electricity generation from RES in the respective scenarios.[306] While the level of system-related curtailment is typically expected to be very limited up to RES generation shares of around 60%, there is some variation in estimated curtailment rates observable across the different scenarios with higher shares of RES generation. These variations can usually be explained by different assumptions e.g. on the availability and expansion of flexibility options such as storage or sector coupling, or differences in other underlying assumptions or constraints. Based on observations from the literature, we assume that the rate of system-related curtailment remains at 0% up to a RES share of 60% and then increases linearly to 10% in the reference scenario and 5% (20%) in the lower (upper) bound scenario. These scenarios are assumed to roughly correspond to scenarios with low, medium and high use of flexibility options. For each country and year, the curtailment rate is then determined by matching the share of RES in electricity generation in the respective country and year (based on historical data or the PRIMES projection) to the projected development below.

[306] Note that these curtailment rates refer to system-related curtailment (resulting from excess supply due to high volumes of RES generation in certain hours) and not grid-related curtailment (resulting from insufficient transmission capacities). For the curtailment rates used for the determination of mitigated emissions, we only consider the former due to lack of literature and data on projected levels of grid-related curtailment. The impact of considering grid-related curtailment is expected to be marginal however, as shown in the sensitivity analysis below, where we consider different levels of grid-related curtailment in addition to system-related curtailment for onshore wind in Germany.

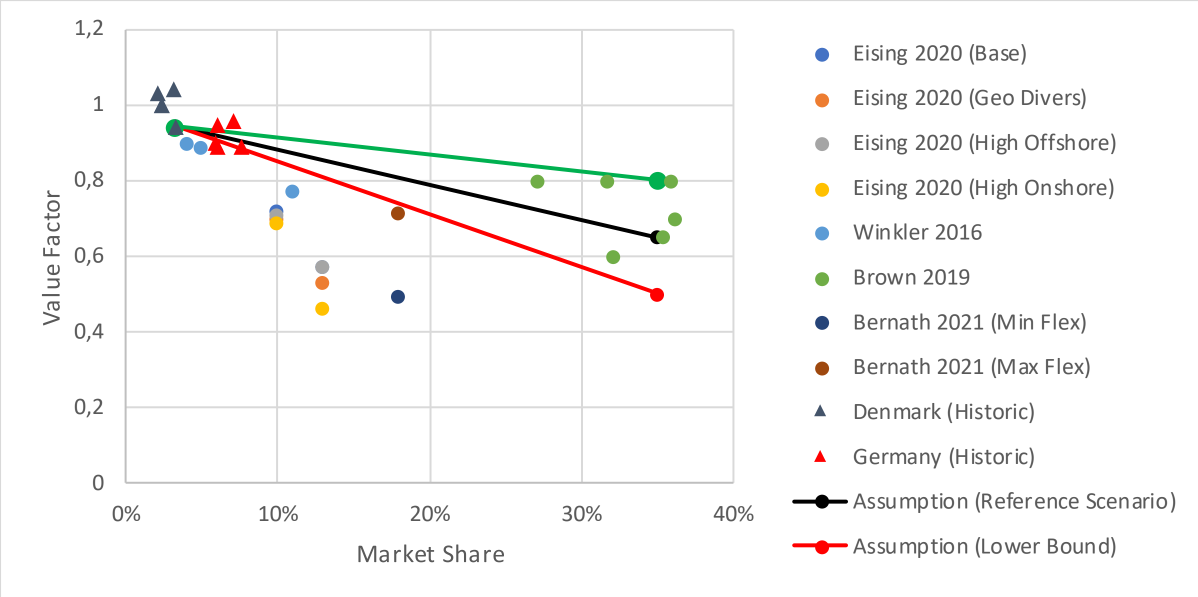
Figure 33: Projected rates of RES curtailment by share of RES in total electricity generation (reference scenario in black, higher/lower bound in red/green)



Source: DIW Berlin.

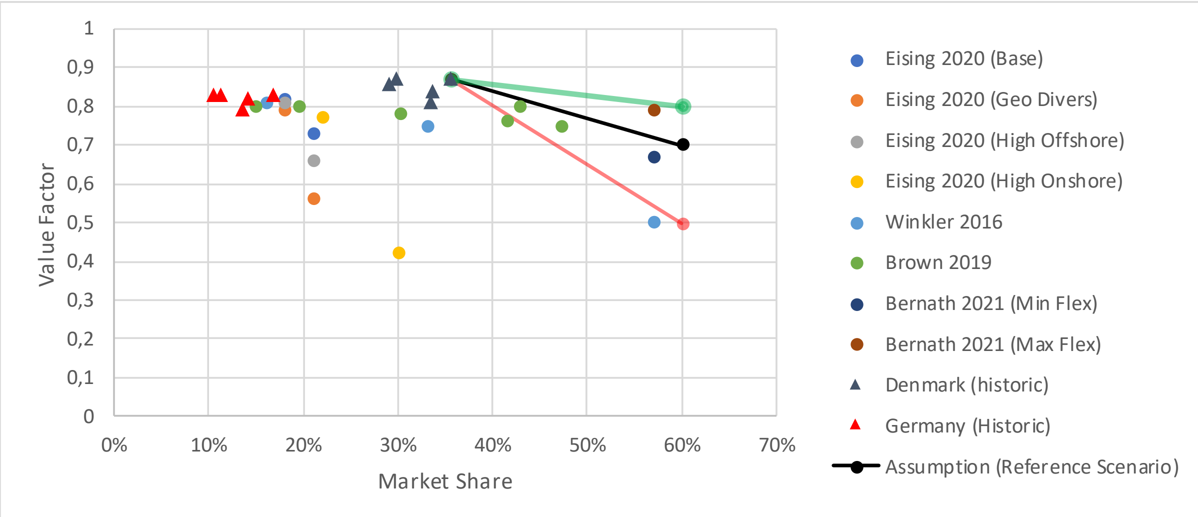
The projection of market values is, similarly to the methodology for curtailment rates, based on a literature review of medium- to long-term energy models and supported by historical data. In the results of these energy models, market values are typically reported as relative value factors, which are defined as the weighted average of the electricity price during the hours of generation of a certain technology compared to the average electricity price over all hours of the year (i.e. the average electricity price for a baseload technology). Figure 34 depicts projected value factors for solar generation in the literature for different scenarios of the share of the technology in total electricity generation (compare Figure 35 for onshore wind and Figure 36 for offshore wind). Based on these values, we derive technology projections of the value factor at increasing market shares of the respective technology. The projections are country-specific since for each country, the projection starts at the most recent observed historical market value of the respective technology (however the projection ends at the same point for all countries, e.g. 0,8 for the upper bound the solar value factor at a market share of 35%). For each technology, country and (future) year, value factors are then determined by matching the market share of the respective year to the projection below. Absolute market values are subsequently calculated as the value factor times the projected electricity price of the respective year.

Figure 34: Projected market value factors for electricity generation from solar (Danish case, reference scenario in black, higher/lower bound in green/red)



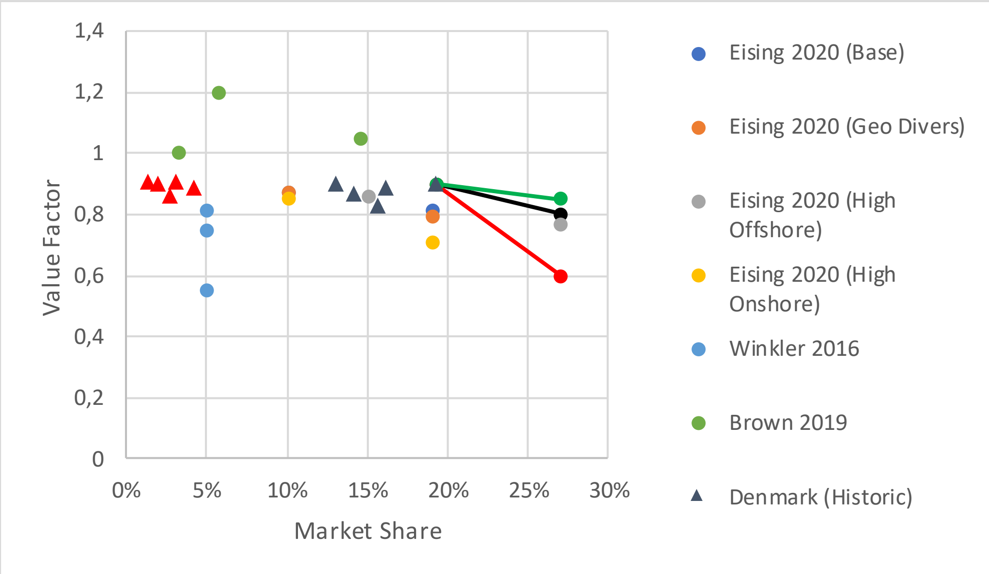
Source: DIW Berlin.

Figure 35: Projected market value factors for electricity generation from on-shore wind (Danish case, reference scenario in black, higher/lower bound in green/red)



Source: DIW Berlin.

Figure 36: Projected market value factors for electricity generation from off-shore wind (Danish case, reference scenario in black, higher/lower bound in green/red)



Source: DIW Berlin.

Annex 2.3 Data for cost-effectiveness study

Table 21: Data sources for input parameters

Input parameter	Data source for backward-looking analysis	Data source for forward-looking analysis
Electricity price (yearly average)	Open Power Systems Data (2020)	PRIMES Ref 2020 scenario (approximated from average production costs in power generation)
CO2 price (yearly average)	Sandbag (2021)	PRIMES Ref 2020 scenario
Electricity generation mix	Eurostat (2021a) Complete energy balances (gross electricity generation)	PRIMES Ref 2020 scenario
Emission factors of fossil electricity generation	Eurostat (2021a) Complete energy balances (gross electricity and heat generation, transformation input to electricity and heat generation) – calculation provided by DG COMP	PRIMES Ref 2020 scenario (fuel input mix), Eurostat (2021a) complete energy balances (derived efficiencies), UBA (2019, fuel emission factors)
Emission factors of fossil heat generation	Eurostat (2021a) Complete energy balances (gross heat generation, transformation input to heat generation)	PRIMES Ref 2020 scenario (fuel input mix), Eurostat (2021a) Complete energy balances (derived efficiencies), UBA (2019, fuel emission factors)
Market values	Open Power Systems Data (2020, hourly generation profile and electricity prices)	PRIMES Ref 2020 scenario (electricity price, generation mix) and literature review-based projections
Curtailment factors	Eurostat (2021a) Complete energy balances (electricity generation mix) and literature review-based projections	PRIMES Ref 2020 scenario (electricity generation mix) and literature review-based projections
Exchange rates	Eurostat (2021b)	

Fuel emission factors	UBA (2019)

Source: DIW Berlin.

Average emission factors of fossil electricity are defined as the total emissions from fossil electricity generation (tCO2) divided by the gross electricity generation of the respective year (MWh). For historic years (up to 2018), these factors are taken directly from the calculation provided by DG Comp, which is based on the transformation input to electricity generation (deriving emissions from fossil generation) and gross electricity generation by fuel type from Eurostat. This indicator includes generation from and transformation input to CHPs, the latter being allocated to electricity and heat using the Finish method. Since the PRIMES scenario results do not provide similarly detailed data, future emission factors were approximated using the projected electricity generation mix. Emissions from fossil electricity generation were derived from the gross electricity generation divided by country-specific efficiencies of fossil electricity and multiplied with the respective fuel emission factors. The efficiencies are based on Eurostat data on the transformation input to and gross generation from electricity producers in 2019 (results are presented in Table 23).

Average emission factors of fossil heat generation are defined as the total emissions from fossil heat generation (in t CO2) divided by the gross heat generation from fossil fuels (in MWh) of the respective year. For historic years (up to 2019), emissions are estimated from the transformation input to heat generation given by Eurostat (using the same methodology and emission factors as for the calculation of emission factors for electricity). This calculation does not include transformation input to and generation from CHPs however, since we assume that CHP-generated heat does not replace heat generation from other CHPs. Similar to the projection of emissions from fossil electricity generation, average emissions from fossil heat generation are approximated using the fuel input mix to district heating units of the respective year and country-specific assumptions on the efficiency of separate fossil heat generation. The efficiencies are based on the Eurostat data on the transformation input to and gross generation from separate heat production in 2019 (results are presented in Table 23).

Table 22: Data sources, gaps and assumptions for support data by considered scheme

Country	Scheme	Data sources	Data gaps	Assumptions
Denmark	RES MT Onshore wind & solar	AURES (2020), DEA (2021)	-	-
	RES Off-shore	AURES (2020)	-	-
	CHP	Data provided by Danish authorities	Efficiency and thermal capacity of supported plants	Overall efficiency of 79% for all plants Ratio of thermal to electric capacity equal to ratio of installed capacities in 2020 in PRIMES scenario
Germany	RES Onshore wind & solar	AURES (2020), BNetzA (2021), Navigant (2019, EEG 2017	List of awarded support levels Yield classes of supported onshore wind installations	All installations received average support level awarded in their respective auction Distribution of yield classes in each auction equal to empirical distribution over all auctions (Navigant, 2019)
	CHP	BNetzA (2021), KWKG 2016	Efficiency, energy carrier and thermal capacity of supported plants Volume of administratively supported plants	Overall efficiency of 81% (new) or 79% (other) plants[307] Ratio of thermal to electric capacity equal to ratio of installed capacities in 2020 in PRIMES scenario Only gas-fired plants supported
	EE	Ifeu and Prognos (2019)	Heat and direct fuel savings (not focus of scheme)	Only electricity savings achieved
Poland	RES Onshore wind & solar	AURES (2020), URE (2021a)	Breakdown of support level by technology	On average, the technologies received the same support level
	CHP	URE (2021b)	Efficiency, energy carrier and thermal capacity of supported plants Volume of administratively supported plants	Overall efficiency of 81% (new) or 79% (other) plants Ratio of thermal to electric capacity equal to ratio of installed capacities in 2020 in PRIMES scenario 20% of auction volume awarded to coal-fired plants
	EE	NEEAP Poland 2017 (only budget)	No data on support paid and savings	Full budget was used for energy efficiency measures, equally split between years Same spending per MWh of saved electricity as in German scheme No additional fuel or heat savings

Source: DIW Berlin.

[307] This corresponds to primary energy savings of about 10% for gas-fired installations, which is the minimum threshold to be considered a high-efficiency cogeneration unit as defined in Directive 2021/27/EU on energy efficiency, hence representing a lower bound assumption (assuming reference values for separate electricity and heat generation as defined in COM Delegated Regulation (EU) 2015/2402, a representative gas-fired CHP with an electrical efficiency of 30% and a heat efficiency of 51% achieves primary energy savings of about 10.4%). A sensitivity analysis is performed for the assumption that all plants have an overall efficiency of 90% (upper bound).

Table 23: Additional assumptions for the assessment of cost-effectiveness

Assumptions	Denmark	Germany	Poland	Sources
Efficiency of electricity generation (incl. CHPs)				Eurostat (2021a) complete energy balances (data for 2018)
Liquid fuels	44%	39%	40%	
Solid fuels	41%	31%	46%	
Natural gas	63%	55%	56%	
Efficiency of heat generation (excl. CHPs)				Eurostat (2021a) complete energy balances (data for 2019)
Liquid fuels	79%	83%	88%	
Solid fuels	90%	64%	88%	
Natural gas	96%	87%	85%	
Full load hours				DEA (2021), Kost et al. (2018), Ligus (2015), Fraunhofer ISE (2018), NREL (2015), Fraunhofer et al. (2019), Eurostat (2021a and 2021c)
Onshore wind	3042	2721	2285	
Offshore wind	4400	-	-	
Solar	981	990	1000	
CHP	6000	5000	5000	
Lifetime				
RES	20 y.	20 y.	20 y.	
CHP[308] new/modernised	-	20 y.	20 y.	
CHPs refurbished	-	10 y.	10 y.	
CHPs existing	End of 2025	-	5 y.	

Source: DIW Berlin.

Annex 2.4 Static simulation study methodology and data annex

Annex 2.4.1 Data structure

Table 24: Time Series Input

Technology	Year	Market Value (in EUR/MWh)	Curtailment (in %)	Emission Savings (tCO2 per MWh)	ETS Price Component (in EUR per MWh)	Discount Factor	Inflation Factor
CHP	2018	39.00	0	0.5	17.7	1.02	1.01
CHP	2019	40.00	0	0.53	17	1.04	1.02
…	...	...	...	...	...	...	...

Source: DIW Berlin.

Table 25: Technology Input

Tech.	Year	Auction	Cost A	Quantity A	Cost B	Quantity B	Cost C	Quantity C	Run Hours
PV	2018	1	38.0	0	59.0	200.6	84.6	1515.5	990
PV	2019	1	38.0	0	50.6	222.2	84.6	1515.5	990
…	...	...	...	...	...	...	...	...	

Source: DIW Berlin.

Annex 2.4.2 Implementation of the reference yield model

The reference yield model is a special feature of the German onshore wind auctions, that aims at "levelling the playing field" between high and low wind yield locations. As this has

[308] Assumptions on the lifetime of supported CHP plants are only relevant for the sensitivity analysis, since in the reference scenario the assumption is that installations only operate until the end of support.

important implications for one of our two main channels ("end of price discrimination"), we included a simplified version of the reference yield model based on the procedure outlined in the German Renewable Energy Sources Act of 2017 in our simulation of the single technology auctions. The version of the reference yield model considered in this analysis is only a partial approximation as it does not entirely capture possible allocative inefficiencies that might arise when more wind-poor locations are awarded support. Likewise, the version of the reference yield does not consider additional benefits such as a steady project pipeline or a more even spatial allocation of wind projects.

Table 26: Reference yield model

Wind Yield	**<70%**	**70-75%**	**75-80%**	**80-85%**	**85-90%**	**90-95%**	**95-100%**	**>100%**
Percentile of Capacity	0.21	0.43	0.65	0.76	0.87	0.93	0.97	1
Correction Factor	1.29	1.25	1.19	1.13	1.09	1.05	1.01	0.89

Source: DIW Berlin.

In our version of the reference yield model, we conduct the following steps:

(i) *Classify installations by cost profiles*

In a first step, we classify the installations into yield categories according to their LCOE. This classification is based on the – reasonable – assumption that installations in more productive locations will have lower average costs of production since they can allocate their fixed costs to a larger quantity of production. Our classification follows the thresholds in the table above and is based on the Navigant (2019).

(ii) *Apply correction factors to bids*

After the installations make their bids but before the supported installations are selected, the bids are adjusted with the following formula:

$$Ajusted\ Bid_i = \frac{Bid_i}{Correction\ Factor_i}$$

Thus, under the reference yield model, installations in lower yield locations see their bids reduced and thereby have an advantage compared to the scenario without the reference yield model.

(iii) *Correction of support payments*

After the clearing price is determined, the clearing price is adjusted to account for the correction factor. In this, the following formula is used to calculate the bids:

$$Effective\ Support_i = \sum_t \left(\max\left(\left(Clearing\ Price_i^{Adj} - MarketValue_{i,t}\right), 0\right)\right) + ETS\ Price\ Compoent_{it}) * Production_{i,t}$$

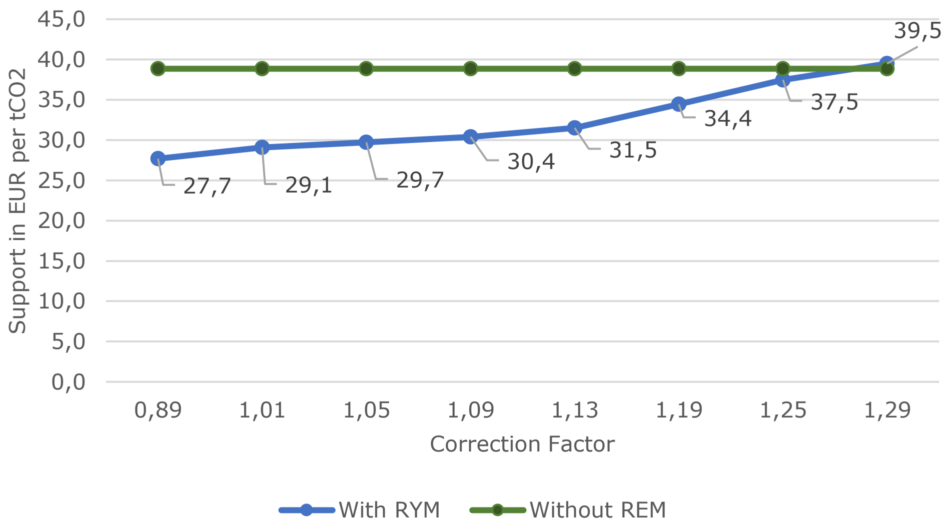
$$where: Clearing\ Price^{Adj} = Clearing\ Price * Correction\ Factor_i$$

Thus, the reference yield model introduces an intra-technology price discrimination in which installations in lower yield locations receive higher support payments, while those in higher yield locations are paid less.

The figure below illustrates this. It is apparent that firms of lower correction factor (i.e.at higher quality wind locations) receive lower renumeration when the reference yield model is applied. This intra-technology price discrimination leads to lower mitigation costs that are observed in our model.

Further, the figure shows that the implementation of the reference yield model does not lead to a reversal in order between the support received by each group, i.e. the lower cost installations do always receive lower support. Our implementation also does not lead to a systematic overcorrection between groups, i.e. lower cost installations still receive the majority of the support awarded in the auctions. There might however be some overcorrections around the cut-offs of each group leading to minor reversals in the ordering of the installations. In reality, there might be a larger degree of overcorrections leading to higher mitigation costs of technology-specific auctions by awarding support to installations in wind-poor locations and resulting allocative inefficiencies.

Figure 37: Support received by installations of differing correction factors



Source: DIW Berlin.

Therefore, our results reflect the reality well, as long as the reference yield model does not heavily overcorrect for the higher cost in low-wind locations. In these cases, the allocation is still efficient, but the reference yield model introduces an element of price discrimination that leads to lower payments to high wind installations. However, when there is a larger effect of overcorrection, the reference yield model might lead to lower allocation efficiency and thus higher costs. As discussed in section 1.3.2, there is a debate about whether the price discrimination or the allocation inefficiency is the stronger effect. Thus, we chose to refer to the implementation of the reference yield model as a partial approximation.

Annex 2.4.3 Maximum and minimum offer by technology

Table 27: Germany (in Eur)

	CHP	EE	PV	Wind Onshore
Min. Offer	40-70	5	38	39.9
Max. Offer	49.9-70	100	84.6	82.3

Source: DIW Berlin.

For CHP we assume flat costs and thereby consider an average CHP plant. We believe this to be reasonable since the revenue expectations for CHP are more predictable than for PV and Wind Onshore. Furthermore, while the prices can be considered as representing the marginal production costs of all other technologies, the offer for CHP represents the fixed premium they bid. The minimum and maximum prices of all other technologies were determined based on a study by Kost et al. (2018).

Table 28: Denmark (in EUR)

	CHP	PV	Wind Onshore	Wind Offshore
Min. Offer	16	0	0	46
Max. Offer	55	4	5	77

Source: DIW Berlin.

Due to the difference in support instruments, the numbers presented here have different implications. While CHP, PV and onshore wind offers are fixed premiums and thus represent the add-on to the expected market value required by the installations, the offshore wind offer is a CfD and thus represents the average costs of the installations. For PV and onshore wind the minimum and maximum bids were determined by applying the distribution of costs from the Danish Energy Agency's LCOE calculator to the bid data. For offshore wind, the LCOE calculator's cost were applied.

Table 29: Poland (in EUR)

	CHP	PV	Wind Onshore
Min. Offer	84.6	45.1	37
Max. Offer	84.6	72	50.9

Source: DIW Berlin.

The costs of Polish PV and wind installations are based on the bids in oversubscribed auctions in the AURES database, and the results were then validated by comparing them to Ligus (2015).[309] The costs of polish CHP installations are based on the cost cited in the EU's state aid investigations of the Polish CHP scheme.

Annex 2.4.4 Maximum available capacity

Table 30: Maximum available capacity (in MW)

	Germany	Denmark	Poland
CHP	391	47	272.7
Energy Efficiency	112-1,004		-
PV	1,560	381.2	842,2
Wind Onshore	252	256.3	534.2
Wind Offshore	-	1,000	-

Source: DIW Berlin.

The maximum available capacity in each year is determined by the average yearly capacity addition assumed in the PRIMES model for the period 2020-2030. For CHP in Poland and Denmark, the PRIMES model includes negative capacity changes so that we decided to take other periods as reference for the capacity addition (Denmark: 2020-2025, Poland: 2040-2045). The value provided by PRIMES for offshore wind in Denmark seemed unreasonable so that we replaced it by the value of 1 GW, which is equivalent to the planned future offshore projects in Denmark.

Annex 2.4.5 Table of auction properties

Table 31: Auction properties

	Germany, 2017	Germany, 2018	Germany, 2019	Denmark, 2018	Denmark, 2019	Poland, 2019
Overall Auction Volume (in mtCO2)	110	91.97	77.55	32.5	31.23	79.22
Auction Volume: Energy Efficiency (in mtCO2)	0,03 (<1%)	0.34 (<1%)	0.34 (<1%)	-	-	-

[309] To our knowledge there is no more recent analysis of Polish LCOE than this study. However, due to the trend of falling LCOEs since 2015 and the study's inclusion of further price components such as balancing costs, we decided to deviate from the absolute values in the paper.

Auction Volume: CHP (in mtCO2)	1,3 (1%)	3.15 (3%)	1.65 (2%)	0.49 (2%)	0.9 (1%)	5.62 (7%)
Auction Volume: PV (in mtCO2)	8,07 (7%)	6.81 (7%)	12.69 (16%)	0.69 (2%)	0.74 (2%)	11.06 (14%)
Auction Volume: Wind Onshore (in mtCO2)	100.6 (92%)	81.67 (89%)	62.87 (81%)	2.79 (9%)	2.68 (9%)	62.54 (79%)
Auction Volume: Wind Offshore (in mtCO2)	-	-	-	28.5 (88%)	27.42 (88%)	-
Support Mechanism: Energy Efficiency	Grant	Grant	Grant	-	-	-
Support Duration: Energy Efficiency	10 years	10 years	10 years	-	-	-
Support Mechanism: CHP	Fixed Premium	Fixed Premium	Fixed Premium	Fixed Premium	Fixed Premium	Sliding Premium
Support Duration: CHP	6 years	6 years	6 years	3 years	3 years	15 years
Support Mechanism: PV	Sliding Premium	Sliding Premium	Sliding Premium	CfD	CfD	Sliding Premium
Support Duration: PV	20 years	20 years	20 years	20 years	20 years	15 years
Support Mechanism: Wind Onshore	Sliding Premium	Sliding Premium	Sliding Premium	CfD	CfD	Sliding Premium
Support Duration: Wind Onshore	20 years	20 years	20 years	20 years	20 years	15 years
Support Mechanism: Wind Offshore	-	-	-	CfD	CfD	-
Support Duration: Wind Offshore	-	-	-	20 years	20 years	-

Source: DIW Berlin.

Annex 2.5 Dynamic simulation methodology and data

Table 32: Long-term cost-potentials for technologies in dynamic simulation

	Wind Offshore	PV	Wind Onshore
Min. Offer [Euro/MWh]	50	38	39.9
Max. Offer [Euro/MWh]	100	84.6	82.3
Potential (without excess) [MW]	15.212	45.465	13.885

Source: DIW Berlin.

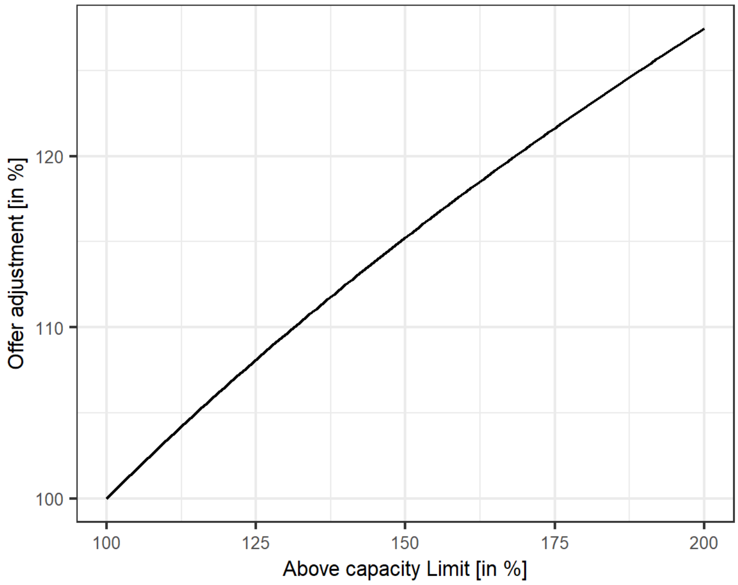
The data assumptions correspond to assumptions made in the static model (and implicitly the cost-effectiveness analysis). The exception are the long-term cost-potentials, given in Table 32. The costs of PV and onshore wind are the same as in the static simulation. Costs of offshore wind are based on an estimate for offshore wind in recent literature (Jansen et. Al., 2020), and the upper bound extrapolated from the full load hour range in Kost et. Al (2018).

The volumes are derived from the differences in installed capacities in the Primes reference scenario for Germany (from 2020 to 2030). These are largely similar to the German renewable targets as formulated in the EEG 2021.

The excess potential factor then linearly extrapolates the cost curve beyond the basic potential. The yearly offer percentage is drawn as an equally spaced sample from the entire technology-specific potential (including the excess), which is sorted by cost.

Modelling of Supply Chain Constraints

Figure 38: Offer adjustment



Source: DIW Berlin.

Above a capacity limit, offers are adjusted upward to reflect capacity shortages and corresponding price increases (this reflects the entire supply chain, as well as availability of skilled labour for installations). The adjustment factor calculation is based on estimated price increases of the capacity utilisation rate in the German construction industry (BBSR, 2017)

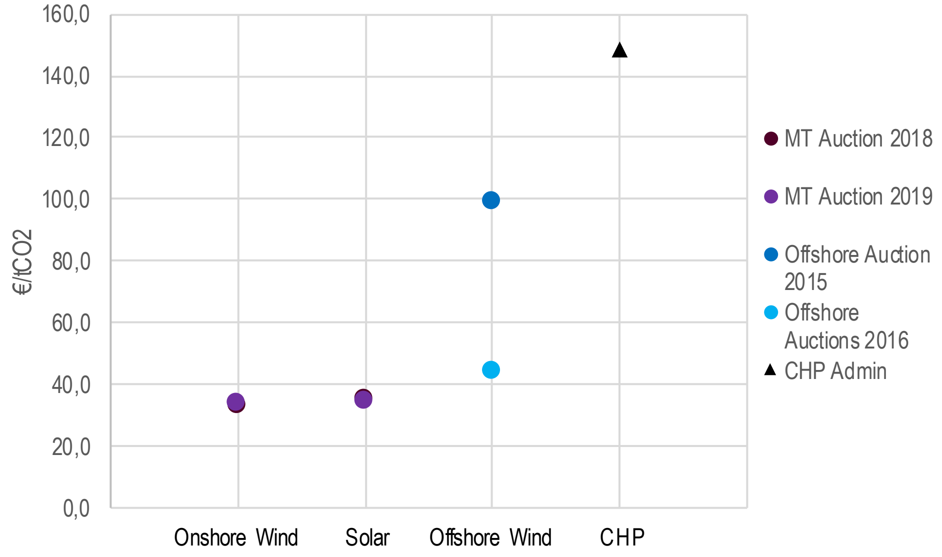
$$Adjustment\ Factor = \left(\frac{Cumulative\ Bid\ Quantity}{Capacity\ Limit}\right)^{0.35}$$

The capacity limit is determined by average installation levels in the last 5 years (and reflects that capacity building in training of skilled labour etc. takes time to adjust). The starting values are assumed to correspond to the currently expected expansion pathway (determined by policy and corresponding to the technology-specific scenario).

Annex 3 Case study extended results and sensitivity

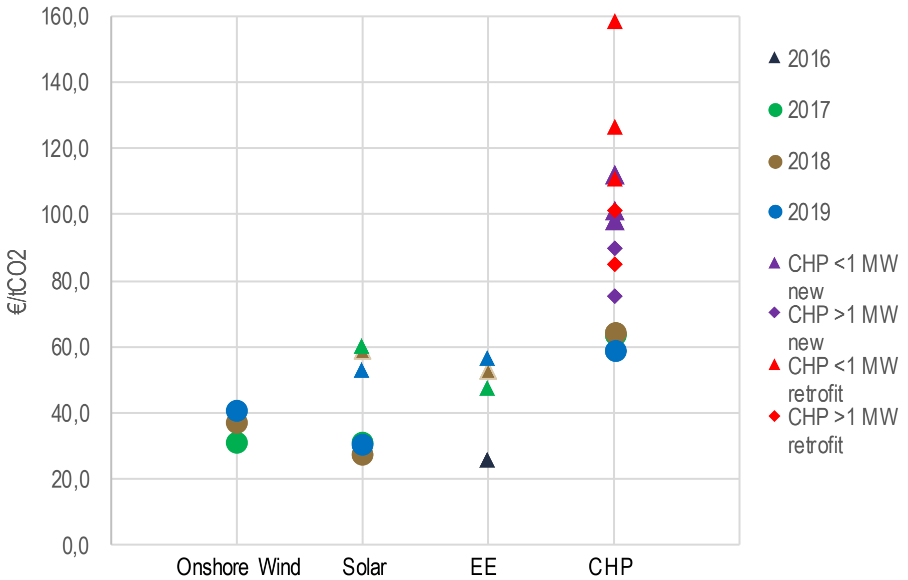
Annex 3.1 Cost-effectiveness: Detailed results

Figure 39: Cost-effectiveness (or carbon mitigation costs) of support schemes considered for Denmark by technology and cohort (grant year or type)



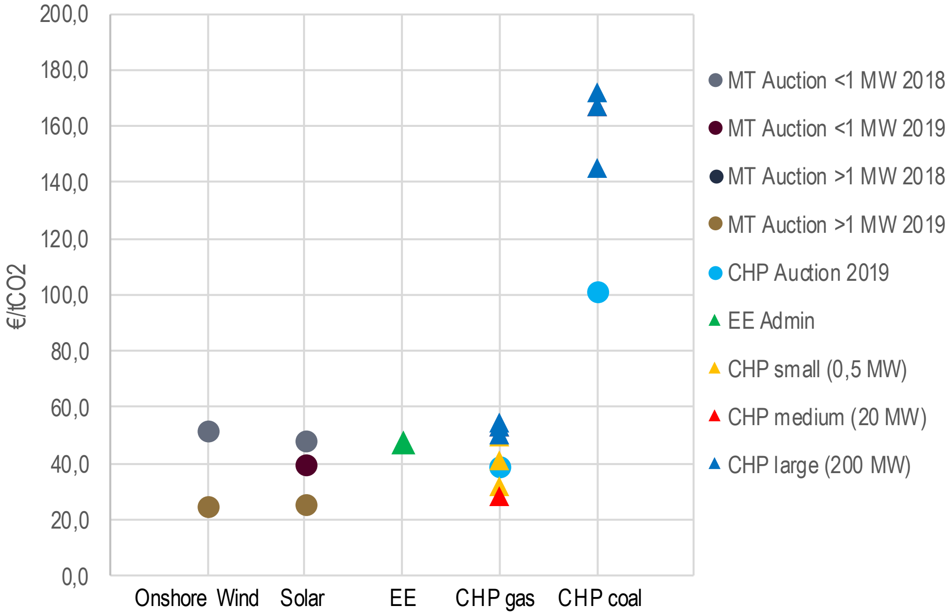
Source: DIW Berlin.

Figure 40: Cost-effectiveness (or carbon mitigation costs) of support schemes considered for Germany by technology and cohort (grant year)



Source: DIW Berlin.

Figure 41: Cost-effectiveness (or carbon mitigation costs) of support schemes considered for Poland by technology and cohort (grant year and/or type)



Source: DIW Berlin.

Annex 3.2 Cost-effectiveness sensitivity

To test the sensitivity of our results to the underlying assumptions, we performed a series of sensitivity analyses for the assumptions as shown in Table 33. The results are shown in Figure 42-Figure 45 for certain cohorts (usually the weighted average of all auctions considered). In each case, only one parameter is changed (compare Table 33). As explained in section 2.3.2 , the results are robust to most assumptions, however the assumption on the discount rate and electricity prices can be more critical as well as the assumption on displaced heat and efficiency of CHPs.

Table 33: Overview of scenarios analysed in the sensitivity analysis

Nr	Variable(s) changed	Position in graphs	Changed to
1	Curtailment, SMNE	Left	Lower projection (increasing to 5%), SMNE = curtailment rate
2	Curtailment, SMNE	Right	Higher projection (increasing to 20%), SMNE = curtailment rate
3	Market values	Left	Lower projection (country- and technology-specific)
4	Market values	Right	Higher projection (country- and technology-specific)
5	Discount rate		5% (base: 2%)
6	Electricity price	Left	- 20% of PRIMES projection
7	Electricity price	Right	+ 20% of PRIMES projection
8	Share marginal non-emitting		2x reference scenario curtailment rate
9	Curtailment	Left	Lower projection (SMNE fixed at reference scenario rate)
10	Curtailment	Right	Higher projection (SMNE fixed at reference scenario rate)

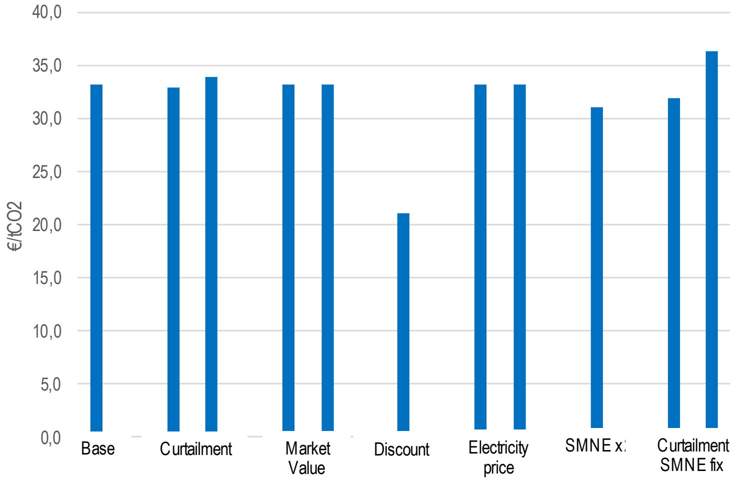
11	Grid-related curtailment (only DE)	Left	Constant at 2019 levels (4% for onshore wind DE, no curtailment of solar in 2019)
12	Grid-related curtailment (only DE)	Right	Linearly decreasing from 4% to 0% in 2045
13	CHP operation	Left	Continuing until end of lifetime (20 years for new/modernised plants) with same support level [310]
14	CHP operation	Right	Continuing until end of lifetime (20 years for new/modernised plants) without support
15	Emission factor heat		CHP-generated heat displaces the average fuel mix in district heating (incl. biomass)
16	Efficiency CHP plants		All supported CHPs assumed to have an overall efficiency of 90% (upper bound)

Source: DIW Berlin.

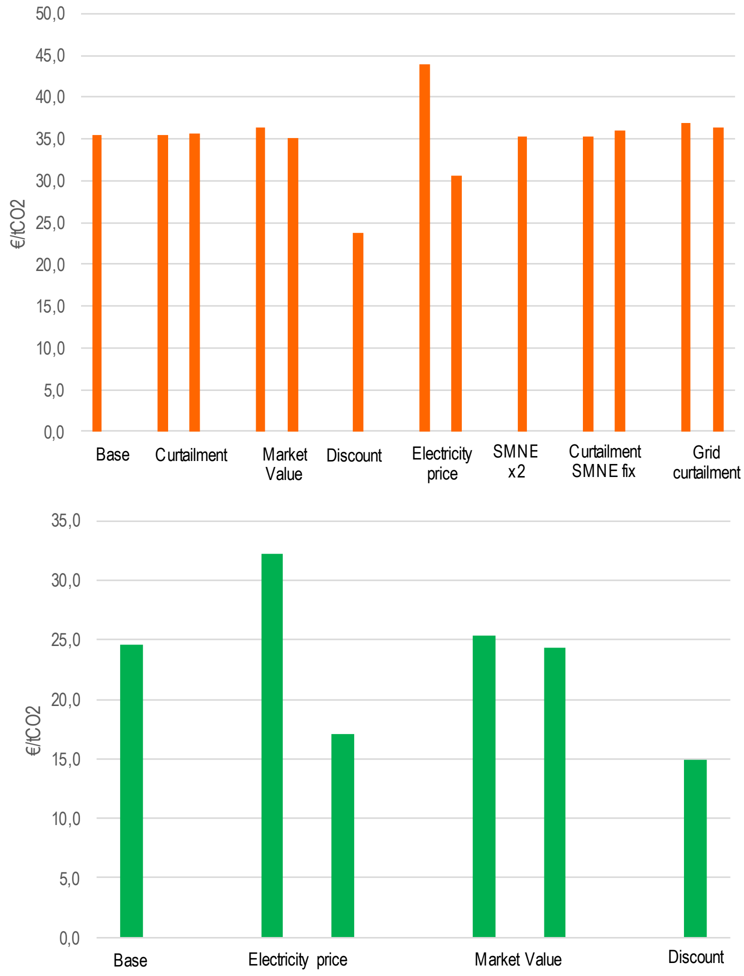
Onshore wind

For onshore wind, besides the discount rate, the largest impact can be observed for the electricity price scenarios in Germany and Poland (fixed premia in Denmark), which assume electricity price variations beyond the CO_2 price. This variation depends on the support instrument, as for CfDs (Poland) the payments are symmetric. Hence, the change in cost-effectiveness as a result of changing the electricity price scenario is also symmetric. For sliding premia, the payments and hence the sensitivity of the cost-effectiveness to the electricity price are asymmetric (better observable in the case of solar, compare Figure 43). Other assumptions do not have a large impact on the results, however the results for Denmark are more sensitive to the assumption of curtailment (for all technologies) since the Danish energy system is projected to reach very high shares of renewable generation much sooner than Germany or Poland.[311]

Figure 42: Sensitivity of cost-effectiveness to variations of different assumptions for supported onshore wind installations in Denmark (top), Germany (middle) and Poland (bottom), considering the weighted average of all auctions



[310] For Danish CHPs, we assume continued operation until the end of 2025 and only consider the support under SA.49918 to continue.
[311] In Poland, RES shares above 50% are not reached in the PRIMES scenario over the time horizon of this study. Since we only assume system-related curtailment to become relevant from RES shares of 60%, the curtailment and SMNE scenarios do not have an impact for Poland.

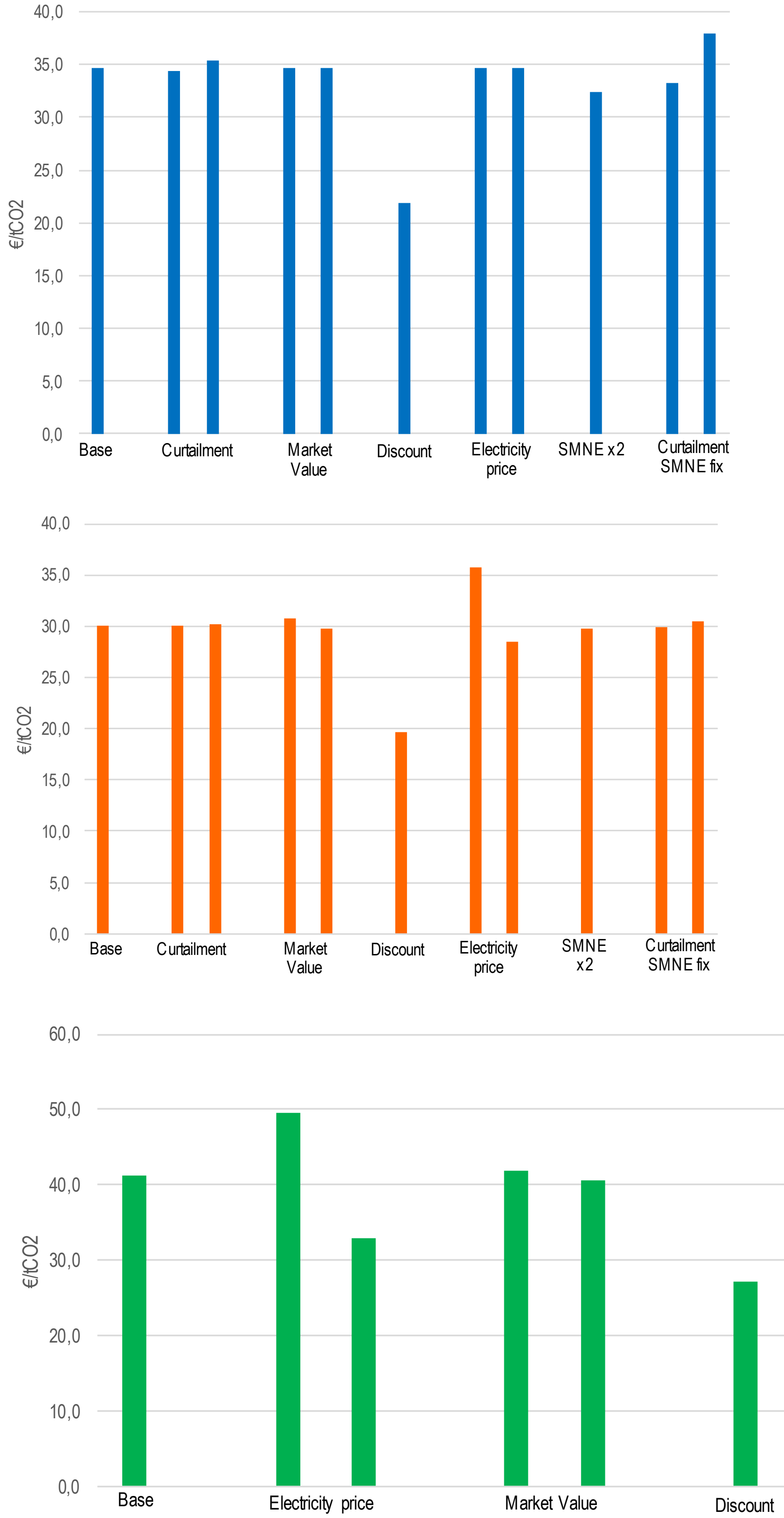


Source: DIW Berlin.

Solar

For the cost-effectiveness of supported solar installations, the sensitivities are similar to the onshore wind case.

Figure 43: Sensitivity of cost-effectiveness to variations in different assumptions for supported solar installations in Denmark (top), Germany (middle) and Poland (bottom), considering the weighted average of all auctions



Source: DIW Berlin.

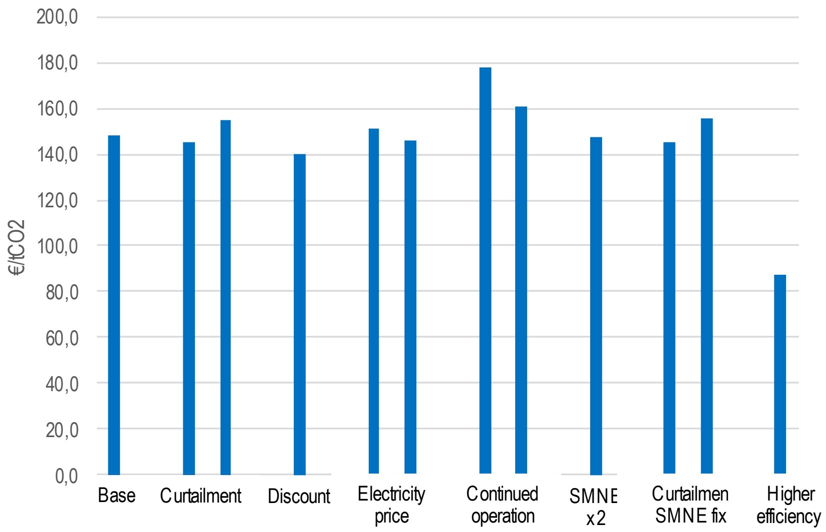
CHP

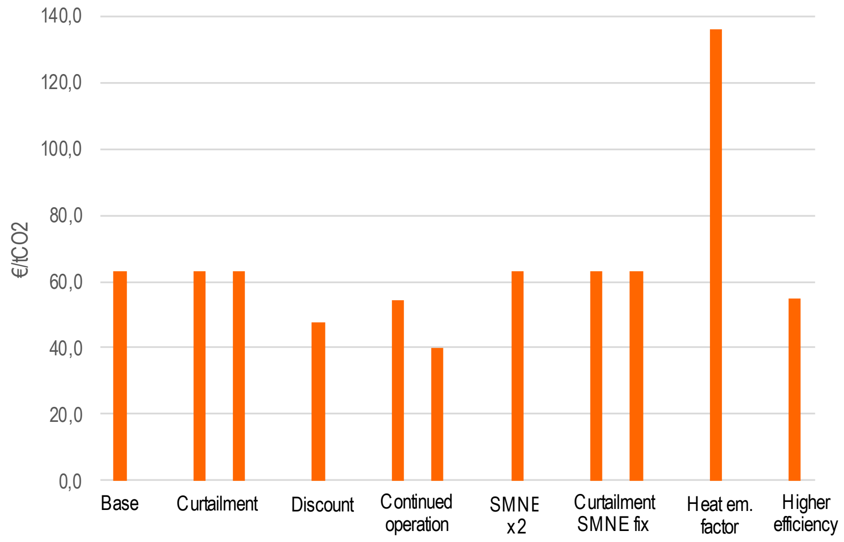
As for the other technologies, the variation of curtailment and SMNE scenarios does not have a large impact on the results. In contrast, three assumptions are more critical for CHPs. First, the assumption on the displaced heat generation mix has a large impact for Germany, where the average heat mix (assumed in the alternative scenario) includes a relevant share of biomass. In Denmark, CHPs did not achieve carbon mitigation when assuming that the average generation mix was displaced, since Denmark has high shares of biomass in the heat sector. For Poland on the other hand, biomass – and hence the assumption on the displaced heat – is not very relevant.

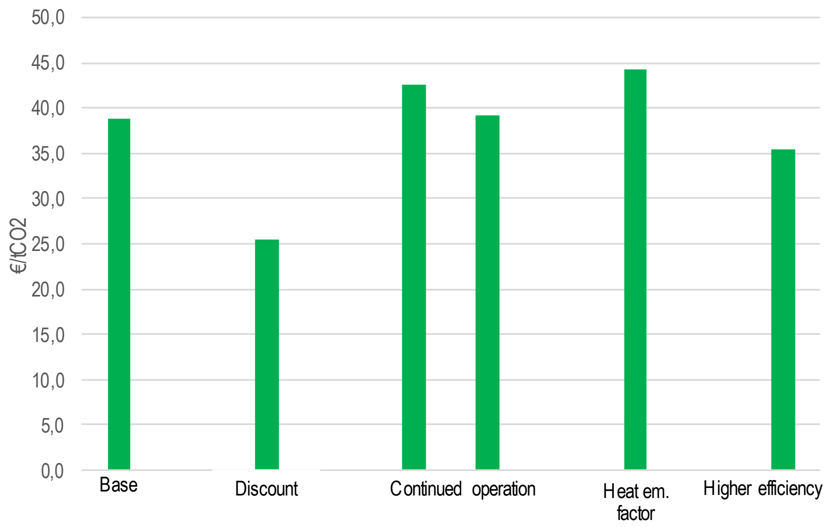
Second, the assumption on the efficiency of supported plants can have a large impact, as can be observed in the Danish case (less so for Germany and Denmark). This assumption is particularly relevant for cases where carbon mitigation is already low (as in Denmark or for coal-/oil-fired plants in Poland/Germany).

Third, the assumption on continued operation of CHPs leads to mixed effects. In Germany, assuming a longer operation improves the cost-effectiveness both when considering continued or no support, since the emission factor of (displaced) fossil heat generation increases significantly around 2030. In Denmark, the cost-effectiveness worsens in both cases due to decreasing emission factors up to 2025. In Poland, the cost-effectiveness is worsened in both cases because the significantly increasing CO_2 prices in the 2030s lead to a higher ETS price component in later years and hence a higher effective support (while at the same time emission factors are slightly decreasing).

Figure 44: Sensitivity of cost-effectiveness to variations of different assumptions for supported CHP installations in Denmark (top), Germany (middle) and Poland (bottom), considering the weighted average of all auctions (administratively supported plants) for Germany and Poland (Denmark)





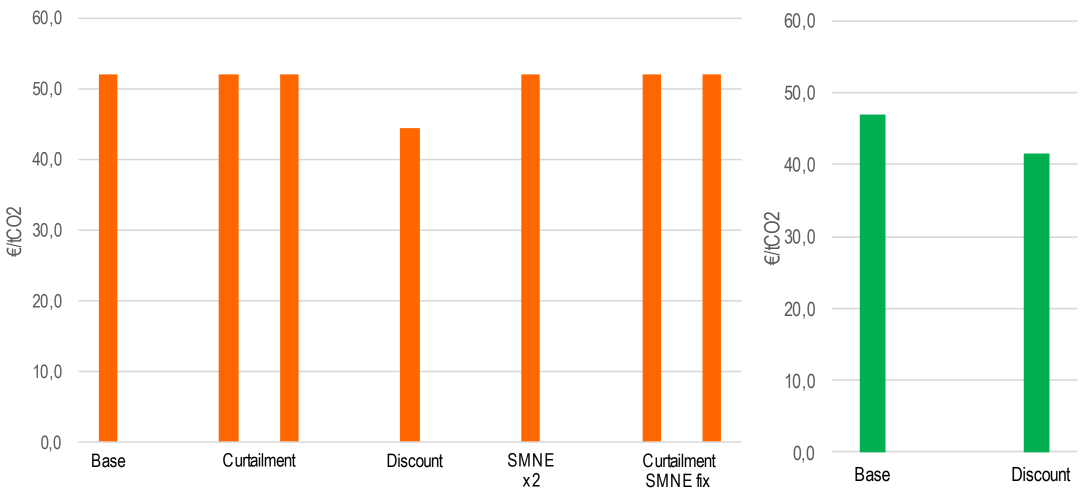


Source: DIW Berlin.

Energy Efficiency

The cost-effectiveness of energy efficiency measures is particularly insensitive to curtailment rate assumptions due to the shorter lifetime of installations (10 years) over which lower levels of curtailment are reached in all scenarios and countries. In addition, the increase of the discount rate to 5% has a lower impact than for other technologies since support is granted in the form of investment aid.

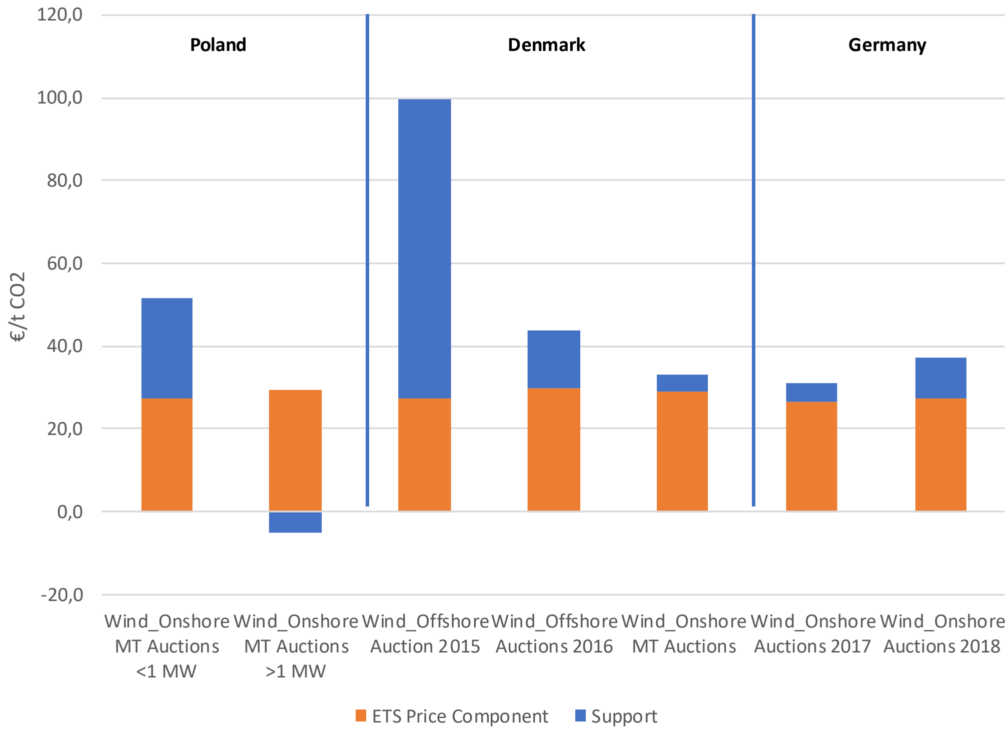
Figure 45: Sensitivity of cost-effectiveness to variations of different assumptions for supported energy efficiency measures in Germany (left) and Poland (right)



Source: DIW Berlin.

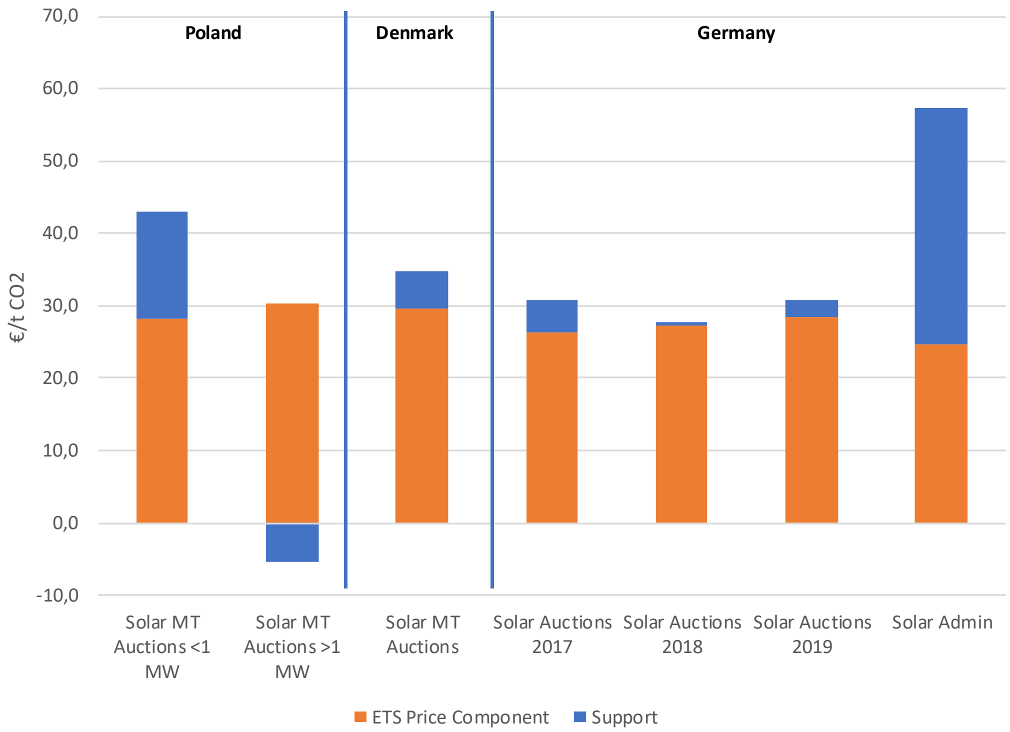
Breakdown of cost-effectiveness

Figure 46: Breakdown of cost-effectiveness in direct support (payments above market values) and ETS price component for onshore and offshore wind



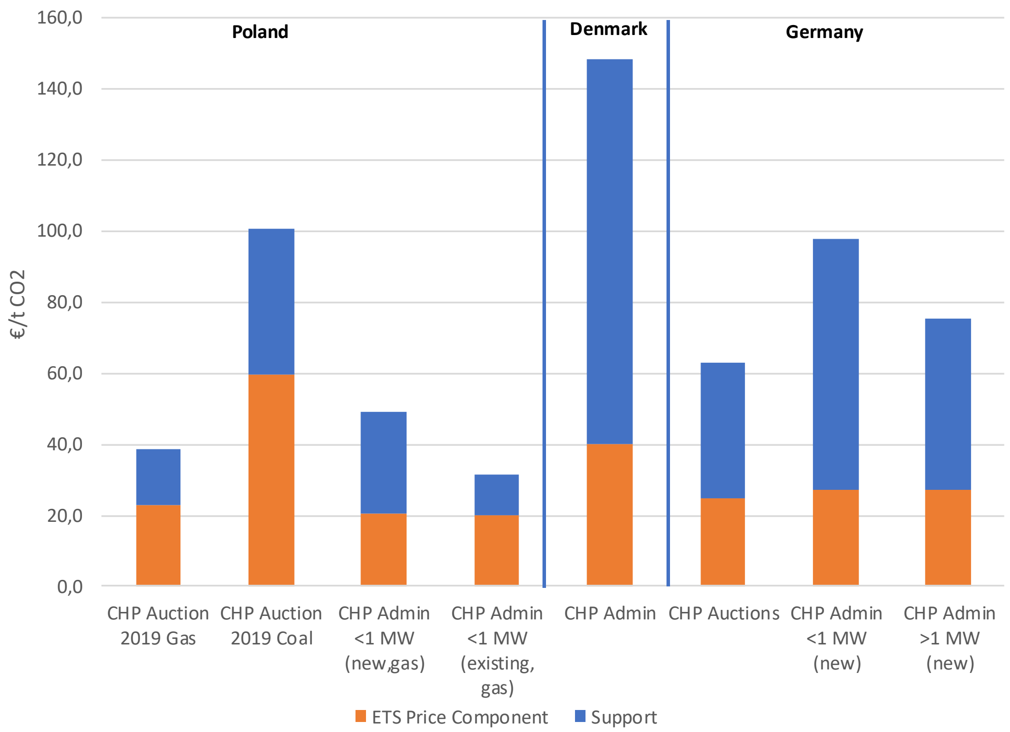
Source: DIW Berlin.

Figure 47: Breakdown of cost-effectiveness in direct support (payments above market values) and ETS price component for solar



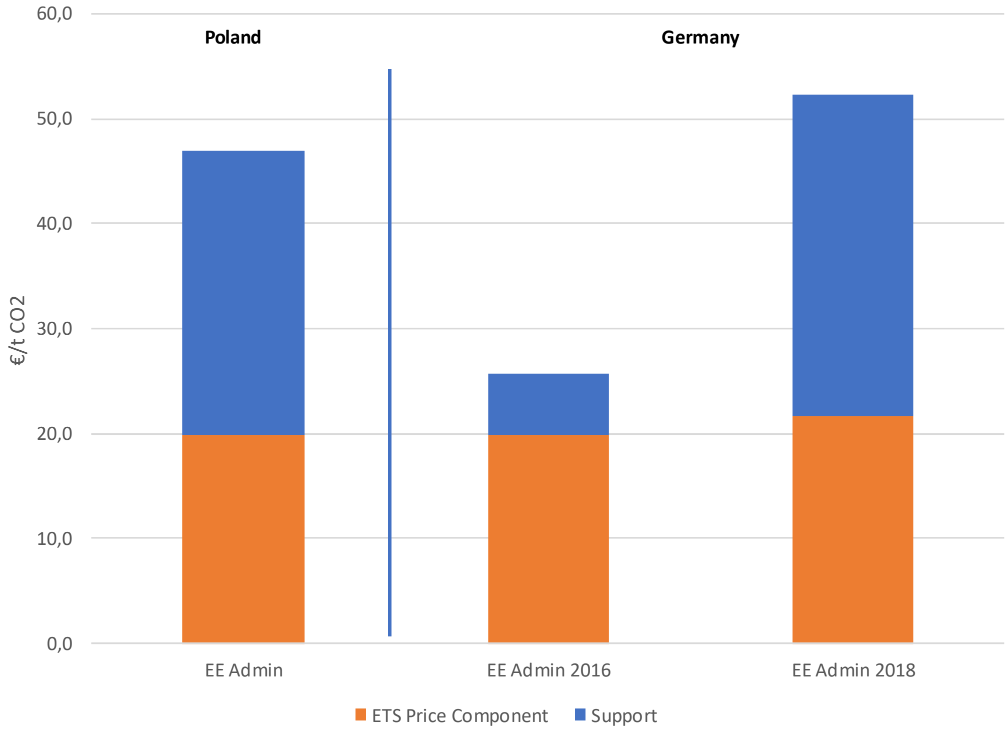
Source: DIW Berlin.

Figure 48: Breakdown of cost-effectiveness in direct support (payments above market values) and ETS price component for CHP



Source: DIW Berlin.

Figure 49: Breakdown of cost-effectiveness in direct support (payments above market values) and ETS price component for energy efficiency



Source: DIW Berlin.

Annex 4 Simulation results and sensitivity

Annex 4.1 Table of auction results

Table 34: Auction results

	Den-mark, 2018	***Den-mark, 2019***	***Ger-many, 2017***	***Ger-many, 2018***	***Ger-many, 2019***	***Poland, 2019***
Multi Tech: Cost-ef-fectiveness –	57.98	60.06	33.80	35.55	37.14	24.37
Single Tech: Cost-ef-fectiveness	62.13	64.39	32.22	37.69	35.28	25.98
Multi Tech: Strike Price	57.98	60.6	33.8	35.55	37.14	24.37
Single Tech: Strike Price En. Efficiency	-	-	110.05	111.1	88.84	-
Single Tech: Strike Price CHP	74.27	88.35	79.17	81.14	79.5	43.71
Single Tech: Strike Price PV	35.69	34.65	29.73	28.17	31.85	26.16
Single Tech: Strike Price Wind Onshore	33.26	34.9	31.38	35.49	34.33	24.35
Single Tech: Strike Price Wind Offshore	65.35	67.71	-	-	-	-

Source: DIW Berlin.

Annex 4.2 Static simulation sensitivity: Partial Approximation of the Reference Yield Model

In order to analyse the importance of our partial approximation of the reference yield model in driving the German results, we run the simulation of the technology-specific scenario with and without the approximation of the reference yield model. The results are shown in the following table and compared to the result of the multi-technology auction in which the reference yield model is never applied. We can observe that the technology-specific auctions have higher overall carbon mitigation costs when our partial approximation of the reference yield model is not applied.

Table 35: Technology-specific

Year	Technology-specific (w/ approximated reference yield model)	Technology-specific (no reference yield model)	Multi-technology
2017	32.22	35.47	33.8
2018	37.69	42.14	35.55
2019	35.28	38.85	37.14

Source: DIW Berlin.

To see how onshore wind drives these results, we compare the technology cost-effectiveness under both scenarios and can see that the mitigation costs of wind fall by 11 to 14% when the reference yield model is applied.

Table 36: Wind-specific

Year	Wind-specific mitigation cost per t CO_2 (w/ approximated reference yield model)	Wind-specific mitigation cost per t CO_2 (no reference yield model)
2017	31.37	34.91
2018	35.49	40.5
2019	34.33	38.85

Source: DIW Berlin.

Thus, we can conclude that our partial approximation of the reference yield model leads to lower prices in the technology-specific auction, as the auctioneer is able to price discriminate between wind turbines. The size and direction of the effect depends on the distribution of correction factors. The model assumes that allocative inefficiencies (i.e., the selection of relatively wind-poor over wind-rich locations) are limited as discussed previously.

Annex 4.3 Static simulation sensitivity: Price Caps

Table 37: Mitigation cost in € per t CO_2 with and without price caps, multi-technology auctions

	Denmark, 2018	Denmark, 2019	Germany, 2017	Germany, 2018	Germany, 2019	Poland, 2019
Without price cap	57.97	60.06	33.81	35.56	37.14	24.37
With Price Cap – 130%	54.64	56.46	33.81	35.56	37.14	24.37
With Price Cap-110%	52.98	54.76	34.12	36.99	37.42	24.37
With Price Cap – 100%	62.14	64.43	35.45	42.17	38.94	25.98

Source: DIW Berlin.

Our simulation study offers the chance of exploring both channels described in the main text: The downward effect on mitigation costs stemming from limiting windfall profits and the upward effect resulting from the now limited supply of low-cost technology. We introduce technology-specific bid ceilings at 100%, 110% and 130% of the prices resulting in the technology-specific auction. An alternative option would be to introduce the price caps according to the price caps that have been used in the technology-specific auctions. However, as Table 38 shows for the case of Germany, the price caps were above the realized auction results in many cases. Since we model our technology cost curves and potential based on these auction results, this means that introducing the technology-specific price caps has no effect in our model. In addition, price caps were not in place for all auctions considered so that introducing price caps based on the technology-specific auction results is the most consistent way and allows us to illustrate the relevant channels.

- The results are presented in Table 37 and discussed below. We find ambiguous effects from the introduction of price caps. Figure 50 to Figure 52 show how the price caps limit the available volume of the low-cost technologies.
- In Denmark, the effect of introducing price caps is most pronounced and opposite to the effect observed in Germany (see below). In fact, we find that the introduction of price caps leads to a substantial decrease in mitigation costs. The reason is that the entire available potential for onshore wind and PV is selected in the multi-technology auctions in both cases so that introducing price caps has no limiting effect. Further, these technologies have substantially lower costs than the price setting offshore wind installations so that substantial wind fall profits existed before. Thus, rather than limiting the supply, introducing price caps does prevent these substantial windfall profits from being realised and thereby lowers mitigation costs. In Figure 50, it is clear to see that both the entire potential for onshore wind and PV are built under the multi-technology auction.
- In Germany, the large potential for onshore wind and PV dominates the multi-technology auctions. Thus, introducing price caps mostly has the effect of awarding support to (slightly) more expensive energy efficiency projects. This leads to higher mitigation costs when price caps are introduced. Given the large potential for PV and onshore wind, these technologies were still price setting in the multi-technology case and no systematic windfall profits where achieved. Figure 51 illustrates how especially the PV potential is reduced under price caps.
- In Poland, onshore wind and PV are the only technologies that are awarded support in the multi-technology auction. The introduction of price caps has no effect since the alternative (CHP) is too expensive and will not be considered in any case in the multi-technology auction. The result is partly an artefact of the model, since the cut-off of the multi-technology auction lies at a plateau of the offer curve and below both the price caps for onshore wind and PV. Figure 52 illustrates this shape of the offer curve.

This indicates that the size and direction of the effect on mitigation costs from the introduction of price ceilings depends on the available potentials as well as the difference in costs by the technologies that receive support in the multi-technology auction. From the table we can also see that the result approaches the result from the technology-specific auctions, when the price cap is equal to the result from the technology-specific auction.[312] Thus, setting the level of the price cap in the multi technology auction introduces a trade-off between limiting the low-cost technology potential and limiting windfall profits.

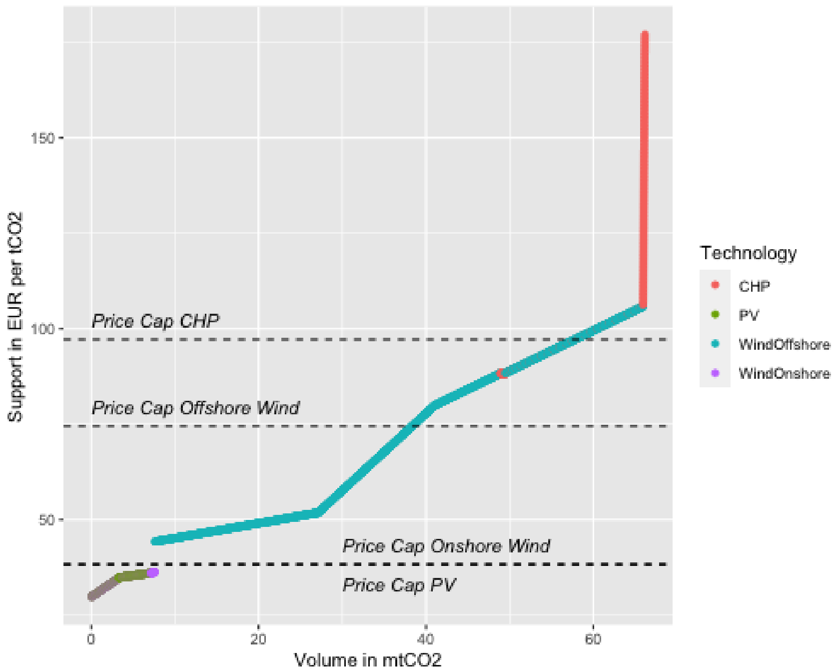
[312] For the German case, it approaches the single technology result without the partial approximation of the reference yield model.

Table 38: Comparison of average strike price and price cap in Germany

Technology	Year	Avg. Strike Price	Avg. Price Cap
Onshore wind	2017	4.63	7.00
Onshore wind	2018	6.04	6.30
Onshore wind	2019	6.20	6.20
PV	2017	5.90	8.89
PV	2018	4.90	8.84
PV	2019	6.09	8.20
CHP	2017	4.99	7
CHP	2018	5.25	7
CHP	2019	5.42	7

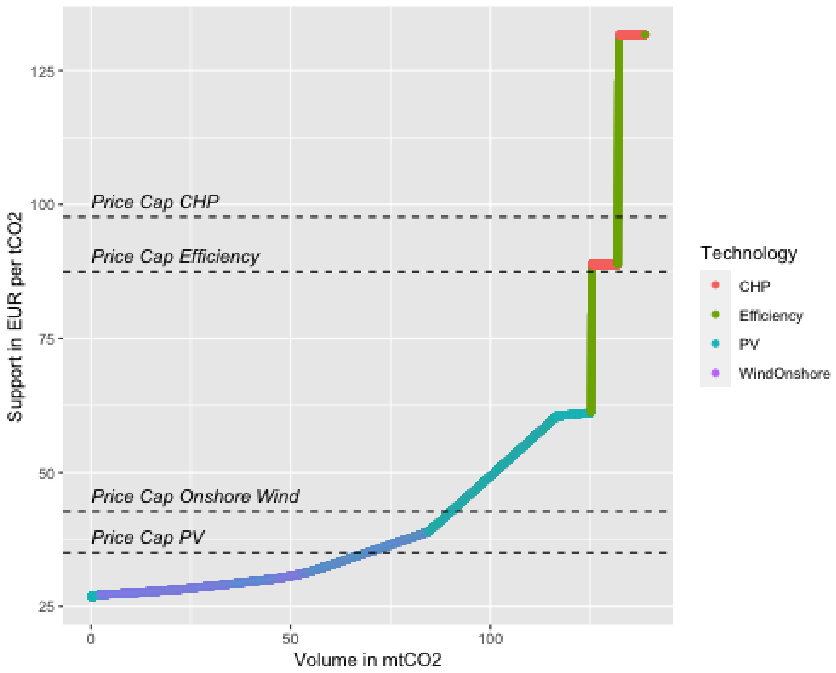
Source: DIW Berlin.

Figure 50: Price Caps (110%) in Denmark, 2019



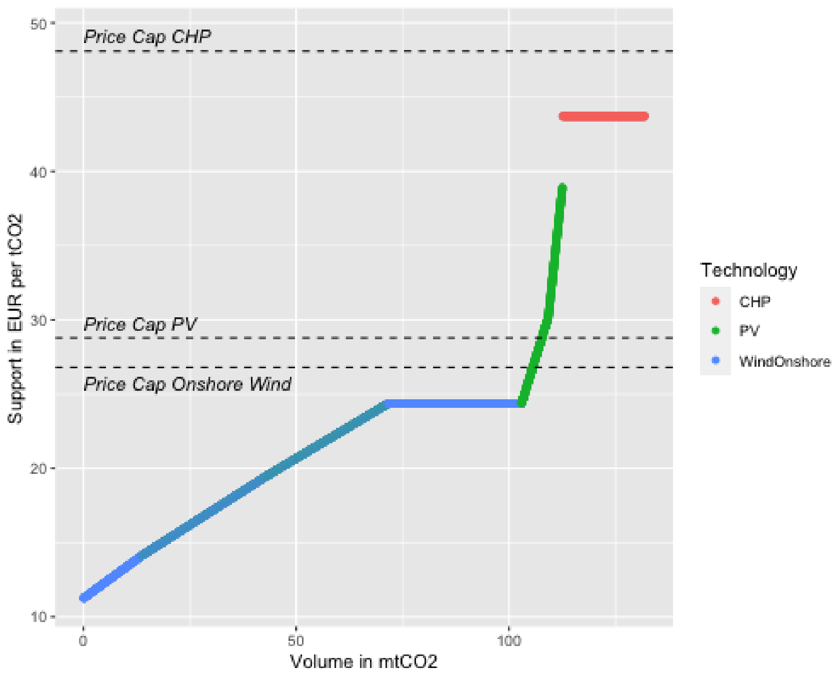
Source: DIW Berlin.

Figure 51: Price Caps (110%) in Germany, 2019



Source: DIW Berlin.

Figure 52: Price Caps (110%) in Poland, 2019

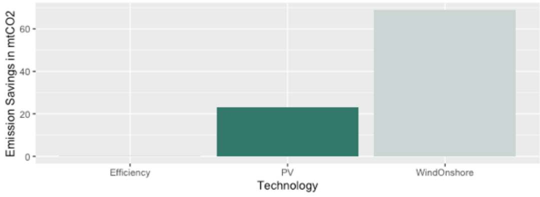


Source: DIW Berlin.

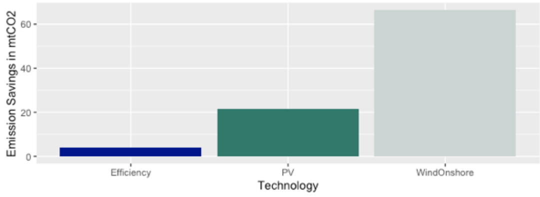
Annex 4.4 Static simulation sensitivity: Increased Capacity of Energy Efficiency

As can be seen in Annex 1.6.7 (Table of Auction Properties), the auction volume of energy efficiency (EE) is only a fraction of the auction volume of other technologies. To see how sensitive our results are to a change in the potential technology mix, we conduct a robustness check of increasing the energy efficiency potential to the level of PV. The following graphs show the technology mix (in terms of mitigated emissions) in three cases: The standard case of small EE potential, the case where EE quantity is increased and the case where EE and total auction volume are increased proportionally. To allow for comparability, we continue to have the same relative distribution of EE project costs.

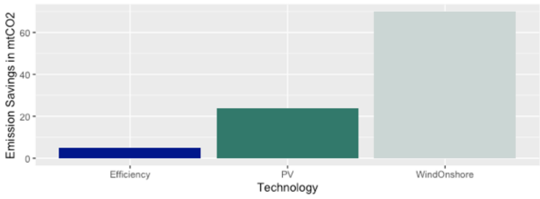
Figure 53: Sensitivity analysis of increased energy efficiency potential



a) Standard Case



b) Increased EE volume



c) Increased EE and total auction volume

Source: DIW Berlin.

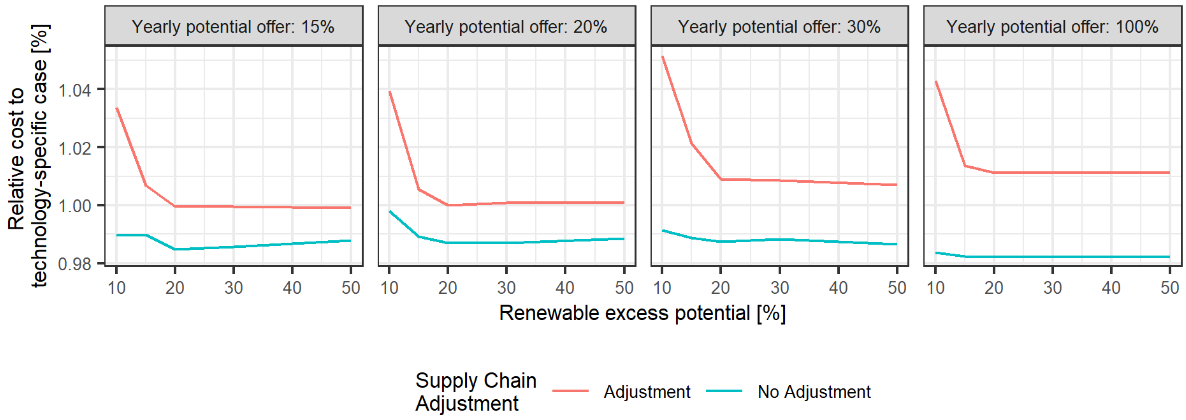
In fact, extending EE capacity alone leads to an increase of EE projects supported in the multi-technology auction from 7,100 MWh to 499,000 MWh as additional cheap EE volume becomes available. This leads to an improvement of overall carbon mitigation costs from 36.33 €/tCO_2 to 35.3 €/tCO_2. This is an example of the crowding out effect as the additional cheap EE potential replaces more expensive wind and PV installations.

If we also increase the auction volume of the multi-technology auction, this leads to a further increase of the supported EE potential to 619,000 MWh. However, it also leads to an increase in mitigation costs to 37 €/tCO_2. The reason for this is that the clearing price increases as additional, more expensive potential is supported in the auction. This negatively affects the cost-effectiveness as all installations are paid this new clearing price. Thus, this is an example of the lack of the ability to price discriminate in multi-technology auctions.

Annex 4.5 Dynamic simulation sensitivities on excess potentials and the yearly offer percentage

In addition to a sensitivity analysis of the renewable potential, we also vary the yearly offer potential. As can be seen in Figure 54, lower yearly potential offers reduce the differences between the multi-technology and technology-specific case both for the scenarios with and without supply chain cost adjustment. The reason is that with a lower yearly potential offer more expensive parts of the cost potential curves are price setting from the start, thus mitigating the differences between the years and scenarios. Nonetheless the overall effects stay similar across the sensitivity analysis.

Figure 54: Sensitivity analysis of yearly potential offer



Source: DIW Berlin.

Annex 5 References for study item 1

The following table provides the list of paper and reports used to address the research questions of study item 1.

Table 39: List of references

Title	Year-Journal	Authors
Measuring cost-effectiveness		
The Economic Cost of Carbon Abatement with Renewable Energy Policies	2017-CER-ETH - Center of Economic Research at ETH Zurich - Economics working paper series	Abrell, J., Kosch, M., and Rausch, S.
Behavioral Science and Energy Policy	2010-Science	Alcott, H., Mullainathan, S.
Cost-Effectiveness Tests to Design CHP Incentive Programs	2014-Report for Oak Ridge National Laboratory	Bluestein, J., Tidball, R., Sreedharan, P., Price, P.,
Zur Forderung erneuerbarer Energien	2004-German Ministry for Economic Affairs and Energy	Board of Academic Advisors-German Ministry for Economic Affairs and Energy
EU climate policy up to 2020: An economic impact assessment	2009-Energy Economics	Böhringer, C., Löschel, A., Moslener, U., Rutherford, T.F
Learning-by-Doing in Solar Photovoltaic Installations	2019-SSRN Electronic Journal	Bollinger, B., Gillingham, K.
Delayed action and uncertain stabilisation targets. How much will the delay cost?	2009-Climatic Change	Bosetti, V., Carraro, C., Sgobbi, A., Tavoni, M.
Delivering Synergies between Renewable Energy and Nature Conservation Messages for Policy Making up to 2030 and Beyond	2015-Report for RSPB/Birdlife Europe by the Institute for European Environmental Policy	Bowyer, C., Tucker, G., Nesbit, M., Baldock, D., Illes, A., Paquel, K.
Instrument Mixes for Environmental Policy: How Many Stones Should be Used to Kill a Bird?	2007-International Review of Environmental and Resource Economics	Braathen, N.A.

Companion Policies under Capped Systems and Implications for Efficiency—The North American Experience and Lessons in the EU Context	2018-RFF report – Resources for the Future	Burtraw, D., Keyes, A., Zetterberg, L.
Unveiling the dynamic relation between R&D and emission abatement National and sectoral innovation perspectives from the EU	2014-Ecological Economics	Corradini, M., Costantini, V., Mancinelli, S., Mazzanti, M.
The cost of delaying action to stem climate change	2014-Report for the White House	Council of Economic Advisers
Interactions between measures for the support of electricity from renewable energy sources and CO_2 mitigation	2009-Energy Policy	De Jonghe, C., Delarue, E., Belmans, R., D'haeseleer, W.
Policy implications of potential conflicts between short-term and long-term efficiency in CO_2 emissions abatement	2008-Ecological Economics	del Río González, P.
Why does the combination of the European Union Emissions Trading Scheme and a renewable energy target makes economic sense?	2017-Renewable and Sustainable Energy Reviews	Del Río González, P.
Quantifying the Total Net Benefits of Grid Integrated Wind	2007-IEEE Transactions on Power Systems	Denny, E., O'Malley, M.
Wind generation, power system operation, and emissions reduction	2006-IEEE Transactions on Power Systems	Denny, E., O'Malley, M.
Towards a climate change ambition that (better) integrates biodiversity and land use	2019-Study of the Institute du Développement Durable et des Relations Internationales (IDDRI)	Deprez, A., Vallejo, L., Rankovic, A.
"Decarbonization and EU ETS Reform: Introducing		
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EU-type carbon regulation and the waterbed effect of green energy promotion	2019-Energy Economics	Eichner, T., Pethig, R.,
Impacts of Renewable Energy on Air Pollutant Emissions	2019-Eionet report ETC/CME 2019/2	ETC/CME
Environmental and technology policies for climate mitigation	2008-Journal of Environmental Economics and Management	Fischer, C., Newell, R.G.
Combining Policies for Renewable Energy	2010-RFF discussion paper – Resources for the Future	Fischer, P., Prenoas, L.
Risk governance guidelines for bioenergy policies	2009-Journal of Cleaner Production	Florin, M.V., Bunting, C.

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The EU ETS and its Interactions with other Climate and Energy Policies	2017-European University Institute - Robert Schuman Centre for Advanced Studies (RSCAS) Policy brief	Marcantonini, C., Teixido-Figueras, J., Verde, S. F., Labandeira, X.
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Ex post-Analyse des Pilotprogramms STEP up!	2019-Study for the Bundesstelle für Energieeffizienz (BfEE)	Ifeu and Prognos
Evaluierung und Weiterentwicklung des Energieeffizienzfonds. Abschlussbericht – Langfassung	2019-Study for the German Federal Ministry for Economic Affairs and Energy	ifeu, Prognos, Stiftung Umweltenergierecht, Fraunhofer ISI
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Time Series. URL: https://data.open-power-system-data.org/time_series/	2020	Open Power System Data
Is the supply chain ready for the green transformation? The case of offshore wind logistics	2017- Renewable and Sustainable Energy Reviews	Poulsen, T., Lema, R.
The marginal system LCOE of variable renewables - Evaluating high penetration levels of wind and solar in Europe	2018-Energy	Reichenberg, L., Hedenus, F., Johnsson, F.
Carbon Price Viewer. URL: https://sandbag.be/index.php/carbon-price-viewer/	2021	Sandbag
Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints	2018-Energy	Schlachtberger, D.P., Brown, T., Schäfer, M., Schramm, S., Greiner, M.
Kohlendioxid-Emissionsfaktoren für die deutsche Berichterstattung atmosphärischer Emissionen (1990-2017)	2019	UBA, Umweltbundesamt
Announcements and RES auctions results. URL: https://www.ure.gov.pl/pl/oze/aukcje-oze/ogloszenia-i-wyniki-auk	2021a	URE, Urzad Regulacji Energetyk
Announcements and CHP auctions results. URL: https://www.ure.gov.pl/pl/efektywnosc-kogenerac/energia-z-kogeneracji/aukcje-chp/9150,Ogloszenia-i-wyniki-aukcji.html	2021b	URE, Urzad Regulacji Energetyki
The role of storage technologies throughout the decarbonisation of the sector-coupled European energy system	2019-Energy Conversion and Management	Victoria, M., Zhu, K., Brown, T., Andresen, G.B., Greiner M.
Impact of renewables on electricity markets– Do support schemes matter?	2016-Energy Policy	Winkler, J., Gaio, A., Pfluger, B., & Ragwitz, M.
The market value of renewable electricity – Which factors really matter?	2016-Applied Energy	Winkler, J., Pudlik, M., Ragwitz, M., Pfluger P.
Cost optimal scenarios of a future highly renewable European electricity system: Exploring the influence of weather data, cost parameters and policy constraints	2018-Energy	Schlachtberger, D.P., Brown, T., Schäfer, M., Schramm, S., Greiner, M.
Case studies: simulation study		
AURES II Auction Database. *Web Resource.* URL: http://aures2project.eu/auction-database/. (Last accessed: 10-02-2021)	2020	AURES Project
Bundesinstitut für Bau-, Stadt- und Raumforschung: URL: https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/bbsr-online/2017/bbsr-online-14-2017.html	2017- BBSR Online Publication	Bundesinstitut für Bau-, Stadt- und Raumforschung
Levelized cost of energy calculator. *Web Resource.* URL: https://ens.dk/en/our-responsibilities/global-cooperation/levelized-cost-	2021	Danish Energy Agency

energy-calculator (Last accessed: 10-02-2021)		
Decision on State Aid Case SA.35486 - Denmark – Aid for electricity generation in industrial combined heat and power plants. Government Report	2015	DG Competition
Decision on State Aid Case SA.42393 - Germany – Reform of support for cogeneration in Germany. Government Report	2016a	DG Competition
Decision on State Aid Case SA.45461 - Germany – Reform of the Renewable Energy Law. Government Report	2016b	DG Competition
Decision on State Aid Case SA.43697 - Poland – Polish support scheme for RES and relief for energy-intensive users. Government Report	2017	DG Competition
Decision on State Aid Case SA.49918 - Denmark – Multi-technology tender 2018-2019. Government Report	2018	DG Competition
Decision on State Aid Case SA.51192 - Poland – CHP support. Government Report	2019	DG Competition
Offshore wind competitiveness in mature markets without subsidy	2020-Nature Energy	Jansen, M., Staffell, I., Kitzing, L. *et al*
Stromgestehungskosten Erneuerbare Energien. *Discussion Paper.* URL: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/DE2018_ISE_Studie_Stromgestehungskosten_Erneuerbare_Energien.pdf (Last accessed: 10-02-2021)	2018	Kost, C., Shivenes S., Jülich, V., Nguyen,H.T., Schlegl, T.
An analysis of competitiveness and potential of renewable energy technologies in Poland	2015-Energy & Environment	Ligus, M.
Evaluierungsbericht der Ausschreibungen für erneuerbare Energien. *Evaluation Report.* URL: https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/bmwi_de/evaluierungsbericht-der-ausschreibungen-fuer-erneuerbare-energien.html (last accessed: 11-02-2021)	2019	Navigant
Methodenpapier zur Bewertung von KWK-Anlagen in mittelfristiger Perspektive bis 2030. Report for the Federal Ministry for Economic Affairs and Energy.	2015	Öko-Institut
Cost-potential curves for onshore wind energy: A high-resolution analysis for Germany	2014-Applied Energy	McKenna, R., Hollnaicher, W. and W. Fichtner
Supply chain of renewable energy technologies in Europe	2017	JRC, Joint Research Centre
Auctions for Renewable Energy Support: Lessons Learned in the AURES Project	2019-IAEE Energy Forum	Kitzing et al.
Vorbereitung und Begleitung bei der Erstellung eines Erfahrungsberichts gemäß § 97 Erneu-erbare Energien-Gesetz; Teilvorhaben II e): Wind an Land. Technical Report.	2019	Deutsche Windguard

ENSPRESO - an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials	2019	Ruiz, P., Nijs, W., Tarvydas, D., Sgobbi, A., Zucker, A., Pilli, R., Jonsson, R., Camia, A., Thiel, C., Hoyer-Klick, C., Dalla Longa, F., Kober, T., Badger, J., Volker, P., Elbersen, B., Brosowski, A., Thrän, D.

Source: Lear and DIW Berlin.

Study Item 2

Annex 6 List of papers and reports for literature review on operating and investment aid

Table 40: List of papers and reports for literature review on operating and investment aid (effectiveness and distortive effects)

Author/Title	Year	Journal
Aceleanu, M.I., Șerban, A.C., Pociovălișteanu, D.M. and Dimian, G.C. A way for a sustainable development in Romania.	2017	Energy Sources
Adamczyk, J., and Magdalena G. "Green certificates as an instrument to support renewable energy in Poland—Strengths and weaknesses."	2020	Environmental Science and Pollution Research
Adigbli, P. and Mahuet, A., 2013. The impact of intermittent sources of energy on the market price of electricity.	2013	Responsabilite et Environnement
Aguirre M, Ibikunle G. Determinants of renewable energy growth: a global sample analysis.	2014	Energy Policy
Ahmadov, A.K. and van der Borg, C. Do natural resources impede renewable energy production in the EU? A mixed-methods analysis.	2019	Energy Policy
Allen, M.L., Allen, M.M., Cumming, D. and Johan, S. Comparative Capitalisms and Energy Transitions: Renewable Energy in the European Union	2019	British Journal of Management
Alola, A.A., Yalçiner, K., Alola, U.V. and Saint Akadiri, S. The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe largest states.	2019	Science of The Total Environment
Alolo, M. and Azevedo, A. The effect of the feed-in-system policy on renewable energy investments: Evidence from the EU countries.	2020	Energy Economics
Andor, M. and Voss, A. Optimal renewable-energy promotion: Capacity subsidies vs. generation subsidies.	2016	Resource and Energy Economics
Ang G, Röttgers D, Burli P. The empirics of enabling investment and innovation in renewable energy.	2017	OECD Environment Working Papers
Angelopoulos, D., Brückmann, R., Jirouš, F., Konstantinavičiūtė, I., Noothout, P., Psarras, J., Tesnière, L. and Breitschopf, B. Risks and cost of capital for onshore wind energy investments in EU countries	2016	Energy & Environment
Angelopoulos, D., Doukas, H., Psarras, J. and Stamtsis, G. Risk-based analysis and policy implications for renewable energy investments in Greece.	2017	Energy Policy
Aranda-Usón, A.; Portillo-Tarragona, P.; Marín-Vinuesa, L.M.; Scarpellini, S. Financial resources for the circular economy: A perspective from businesses.	2019	Sustainability
Baldwin E, Carley S, Brass JN, Maclean LM. Global renewable electricity policy: a comparative policy analysis of countries by income status.	2017	Journal of Comparative Policy Analysis: Research and Practice
Banja, M., Jégard, M., Motola, V. and Sikkema, R. Support for biogas in the EU electricity sector–A comparative analysis.	2019	Biomass and Bioenergy
Barreiro Carril, M.C., Spanish Tax Credit for Investments in Environmental Protection: An Example of a Tax Incentive Compatible with EU Rules on State Aid.	2015	WU International Taxation Research Paper Series
Baltputnis, K., Broka, Z. and Sauhats, A. Assessing the Value of Subsidizing Large CHP Plants.	2018	Proceedings from the 15th International Conference

		on the European Energy Market (EEM)
Barton, B. and Schütte, P. Electric vehicle law and policy: a comparative analysis.	2017	Journal of Energy & Natural Resources Law
Bellantuono, G. The misguided quest for regulatory stability in the renewable energy sector.	2017	The Journal of World Energy Law & Business
Bersalli, G., Menanteau, P. and El-Methni, J. Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America.	2020	Renewable and Sustainable Energy Reviews
Bergek A, Jacobsson S. Are tradable green certificates a cost-efficient policy	2010	Energy Policy
Best R, Burke PJ. Adoption of solar and wind energy: the roles of carbon pricing and aggregate policy support.	2018	Energy Policy
Blom, M., Vergeer, R., Wielders, L., Schep, E., Hof, B., Buunk, E. and Tieben, B. Evaluatie van de SDE+-regeling.	2016	University of Amsterdam Digital Academic Repository
Boehringer, C.; Cuntz, A.N.; Harhoff, D.; Asane-Otoo, E. The Impacts of Feed-in Tariffs on Innovation: Empirical Evidence from Germany	2014	SSRN CESigo Working Paper Series
Bolkesjoe TF, Eltvig PT, Nygaard E An econometric analysis of support scheme effects on renewable energy investments in Europe.	2014	Energy Procedia
Botta, E. An experimental approach to climate finance: the impact of auction design and policy uncertainty on renewable energy equity costs in Europe.	2019	Energy Policy
Bougette, P. and Charlier, C. La difficile conciliation entre politique de concurrence et politique industrielle: le soutien aux énergies renouvelables	2016	Revue économique
Brijs, T., De Vos, K., De Jonghe, C. and Belmans, R., Statistical analysis of negative prices in European balancing markets.	2015	Renewable Energy
Broin, E.Ó., Nässén, J. and Johnsson, F. Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010.	2015	Applied Energy
Buckman G. The effectiveness of Renewable Portfolio Standard banding and carveouts in supporting high-cost types of renewable electricity.	2011	Energy Policy
Butler L, Neuhoff K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development.	2008	Renewable Energy
Cansino JM, Pablo-Romero M del P, Román R, Yñiguez R. Tax incentives to promote green electricity: an overview of EU-27 countries.	2010	Energy Policy
Carley S, Baldwin E, MacLean LM, Brass JN. Global expansion of renewable energy generation: an analysis of policy instruments.	2017	Environmental and Resource Economics
Ćetković, S. and Buzogány, A. Varieties of capitalism and clean energy transitions in the European Union: When renewable energy hits different economic logics	2016	Climate Policy
Charlier, D. Energy efficiency investments in the context of split incentives among French households.	2015	Energy Policy

Choi H, Anadón LD. The role of the complementary sector and its relationship with network formation and government policies in emerging sectors: the case of solar photovoltaics between 2001 and 2009.	2014	Technological Forecast Social Change
Christensen, J.L. and Hain, D.S. Knowing where to go: The knowledge foundation for investments in renewable energy.	2017	Energy Research & Social Science
Chyong, C., Pollitt, M. and Cruise, R. Can wholesale electricity prices support “subsidy-free” generation investment in Europe?	2019	Cambridge University Online Repository
Cludius, J., Hermann, H., Matthes, F.C. and Graichen, V. The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications.	2014	Energy economics
Criscuolo C, Menon C. Environmental policies and risk finance in the green sector: cross-country evidence.	2015	Energy Policy
Cumming D, Henriques I, Sadorsky P “Cleantech” venture capital around the world.	2016	International Review of Financial Analysis
De Vos, K. Negative wholesale electricity prices in the German, French and Belgian day-ahead, intra-day and real-time markets.	2015	The Electricity Journal
del Río, P "The dynamic efficiency of feed-in tariffs: The impact of different design elements."	2012	Energy Policy
del Río P, Gual MA. An integrated assessment of the feed-in tariff system in Spain.	2006	Energy Policy
del Río P, Linares P. Back to the future? Rethinking auctions for renewable electricity support.	2014	Renewable and Sustainable Energy Review
del Río P, Tarancón M, ángel. Analysing the determinants of on-shore wind capacity additions in the EU: an econometric study.	2012	Applied Energy
del Río P, Unruh G. Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity.	2007	Renewable and Sustainable Energy Review
Deller, D., Ennis, S., Enstone, B., Głowicka, E., Hofmann M., Mäkelä, P., Snaith, G., and Witte, S. 2020. Retrospective evaluation support study on State aid rules for environmental protection and energy.	2019	Government Reports and Commissioned Studies
Dijkgraaf E, van Dorp TP, Maasland E. On the effectiveness of feed-in tariffs in the development of photovoltaic solar.	2018	Energy Journal
Dincer, H., Yüksel, S. and Martinez, L. Balanced scorecard-based Analysis about European Energy Investment Policies: A hybrid hesitant fuzzy decision-making approach with Quality Function Deployment.	2019	Expert Systems with Application
Dong CG. Feed-in tariff vs. renewable portfolio standard: an empirical test of their relative effectiveness in promoting wind capacity development.	2012	Energy Policy
Duruisseau, K The development of ground-based photovoltaic power plants in the territories of southern France State of play, factors and territorialization	2015	Bulletin de la Société Géographique de Liège
Egli, F. Renewable energy investment risk: An investigation of changes over time and the underlying drivers.	2020	Energy Policy
Eleftheriadis IM, Anagnostopoulou EG Identifying barriers in the diffusion of renewable energy sources.	2015	Energy Policy
Engström, G., Gars, J., Jaakkola, N., Lindahl, T., Spiro, D. and van Benthem, A.A. What policies address both the coronavirus crisis and the climate crisis?	2020	Environmental and Resource Economics

European Commission. Renewable Energy Progress Report COM(2020)952	2020	Government Reports and Commissioned Studies
European Commission. fifth Report on the state of the energy union COM(2020)950 (including annex reports, progress report on the internal energy market and Energy subsides in the EU	2020	Government Reports and Commissioned Studies
European Commission. fifth Report on the state of the energy union: Progress report on competitiveness COM(2020)953	2020	Government Reports and Commissioned Studies
European Commission. In-Depth Analysis in Support of the commission communication com (2018) 773: A Clean Planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy	2018	Government Reports and Commissioned Studies-
Eyraud L, Clements B, Wane A. Green investment: Trends and determinants.	2013	Energy Policy
Fouquet D, Johansson TB. European renewable energy policy at crossroads-focus on electricity support mechanisms.	2008	Energy Policy
García-Álvarez MT, Cabeza-García L, Soares I. Analysis of the promotion of on-shore wind energy in the EU: Feed-in tariff or renewable portfolio standard?	2017	Renewable Energy
Gavard C. Carbon price and wind power support in Denmark.	2016	Energy Policy
Gawel, E. and Lehmann, P. Should renewable energy policy be 'renewable'?	2019	Oxford Review of Economic Policy
Geddes A, Schmidt TS, Steffen B. The multiple roles of state investment banks in low-carbon energy finance: an analysis of Australia, the UK and Germany.	2018	Energy Policy
Gephart, M., Klessmann, C. and Wigand, F. Renewable energy auctions–When are they (cost-) effective?	2017	Energy & Environment
Gillingham, K., Keyes, A. and Palmer, K. Advances in evaluating energy efficiency policies and programs.	2018	Annual Review of Resource Economics
Gippner, O. and Torney, D. Shifting policy priorities in EU-China energy relations: Implications for Chinese energy investments in Europe.	2017	Energy Policy
Gökgöz, F. and Güvercin, M.T. Energy security and renewable energy efficiency in EU.	2018	Renewable and Sustainable Energy Reviews
Grafström, J.; Lindman, Å. Invention, innovation and diffusion in the European wind power sector.	2017	Technological Forecasting and Social Change
Grösche, P., Schmidt, C.M. and Vance, C. Identifying free-riding in home-renovation programs using revealed preference data.	2013	Jahrbücher für Nationalökonomie und Statistik
Gürtler, K., Postpischil, R. and Quitzow, R. The dismantling of renewable energy policies: The cases of Spain and the Czech Republic	2019	Energy Policy
Gutermuth PG. Financial measures by the state for the enhanced deployment of renewable energies	1998	Solar Energy
Haas R, Panzer C, Resch G, Ragwitz M, Reece G, Held A. A historical review of promotion strategies for electricity from renewable energy sources in EU countries.	2011	Renewable and Sustainable Energy Review

Hansen, K., Mathiesen, B.V. and Skov, I.R. Full energy system transition towards 100% renewable energy in Germany in 2050.	2019	Renewable and Sustainable Energy Review
Heiskanen E, Jalas M, Juntunen JK, Nissilä H. Small streams, diverse sources: who invests in renewable energy in Finland during the financial downturn?	2017	Energy Policy
Hitaj, C.; Löschel, A. The Impact of a Feed-In Tariff on Wind Power Development in Germany.	2019	Resource Energy Economics
Höckner, J., Voswinkel, S. and Weber, C. Market distortions in flexibility markets caused by renewable subsidies–The case for side payments.	2020	Energy Policy
Hu, J., Harmsen, R., Crijns-Graus, W., Worrell, E. and van den Broek, M., 2018. Identifying barriers to large-scale integration of variable renewable electricity into the electricity market: A literature review of market design.	2018	Renewable and Sustainable Energy Review
Huntington, S.C., Rodilla, P., Herrero, I. and Batlle, C. Revisiting support policies for RES-E adulthood: Towards market compatible schemes.	2017	Energy Policy
Inês, C., Guilherme, P.L., Esther, M.G., Swantje, G., Stephen, H. and Lars, H. Regulatory challenges and opportunities for collective renewable energy prosumers in the EU.	2020	Energy Policy
Isberg, U., Jonsson, L., Pädam, S., Hallberg, A., Nilsson, M. and Malmström, C. Report for Swedish Environmental Agency: Klimatklivet–en utvärdering av styrmedlets effekter. WSP Sverige AB, Rapport på uppdrag av Naturvårdsverket	2017	Government Reports and Commissioned Studies-
Iychettira, K.K., Hakvoort, R.A. and Linares, P. Towards a comprehensive policy for electricity from renewable energy: An approach for policy design.	2017	Energy Policy
Jääskeläinen, J., Huhta, K. and Lehtomäki, J. Ensuring generation adequacy in Finland with smart energy policy-How to save Finnish CHP production?	2018	Presented at 15th International Conference on the European Energy Market
Jacobsson S, Lauber V. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology.	2006	Energy Policy
Jenner S, Groba F, Indvik J. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries.	2013	Energy Policy
Johnstone N, Haščič I, Popp D. Renewable energy policies and technological innovation: evidence based on patent counts.	2010	Environmental and Resource Economics
Kelsey, N. and Meckling, J. Who wins in renewable energy? Evidence from Europe and the United States.	2018	Energy Research & Social Science
Kester, J., Noel, L., de Rubens, G.Z. and Sovacool, B.K. Policy mechanisms to accelerate electric vehicle adoption: a qualitative review from the Nordic region.	2018	Renewable and Sustainable Energy Reviews
Kilinc-Ata N. The evaluation of renewable energy policies across EU countries and US states: an econometric approach	2016	Energy for Sustainable Development
Kim J, Park K. Financial development and deployment of renewable energy technologies.	2016	Energy Economics
Kim, K.; Heo, E.; Kim, Y. Dynamic Policy Impacts on a Technological-Change System of Renewable Energy: An Empirical Analysis.	2017	Environmental and Resource Economics

Kim, K.; Kim, Y. Role of policy in innovation and international trade of renewable energy technology: Empirical study of solar PV and wind power technology.	2015	Renewable and Sustainable Energy Reviews
Kitzing, L., Islam, M. and Fitch-Roy, O. Comparison of auctions and alternative policy options for RES-E support.	2017	AURES Project Report
Lauber V. REFIT and RPS: Options for a harmonised Community framework.	2004	Energy Policy
Leete S, Xu J, Wheeler D. Investment barriers and incentives for marine renewable energy in the UK: an analysis of investor preferences.	2013	Energy Policy
Lévay, P.Z., Drossinos, Y. and Thiel, C. The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership	2017	Energy Policy
Li S-J, Chang T-H, Chang S-L. The policy effectiveness of economic instruments for the photovoltaic and wind power development in the European Union.	2017	Renewable Energy
Linnerud K, Holden E. Investment barriers under a renewable-electricity support scheme: differences across investor types.	2015	Energy
Lipp J. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom.	2007	Energy Policy
Liu, W., Zhang, X. and Feng, S. Does renewable energy policy work? Evidence from a panel data analysis.	2019	Renewable Energy
Maillo, J. Balancing Environmental Protection, Competitiveness and Competition: A Critical Assessment of the GBER and EEAG.	2017	European State Aid Quarterly
Marinaș, M.C., Dinu, M., Socol, A.G. and Socol, C. Renewable energy consumption and economic growth. Causality relationship in Central and Eastern European countries.	2018	Public Library of Science (PLoS) one
Marques AC, Fuinhas JA Are public policies towards renewables successful? Evidence from European countries.	2012	Renewable Energy
Marques AC, Fuinhas JA Do energy efficiency measures promote the use of renewable sources?	2011	Environmental Science and Policy
Marques, AC, Fuinhas, JA, Pereira, DS. The dynamics of the short and long-run effects of public policies supporting renewable energy: A comparative study of installed capacity and electricity generation	2019	Economic Analysis and Policy
Matthäus, D. and Mehling, M. De-risking Renewable Energy Investments in Developing Countries: A Multilateral Guarantee Mechanism.	2020	Joule
Mazzucato, M. and Semieniuk, G. Financing renewable energy: Who is financing what and why it matters.	2018	Technological Forecasting and Social Change
Menanteau P, Finon D, Lamy ML. Prices versus quantities: Choosing policies for driving technical change or a rent-generating machine? Lessons from Sweden	2003	Energy Policy
Mezősi, A., Kácsor, E., Beöthy, Á., Törőcsik, Á. and Szabó, L. Modelling support policies and renewable energy sources deployment in the Hungarian district heating sector	2017	Energy & Environment
Michalena, E. and Hills, J.M. Stepping up but back: How EU policy reform fails to meet the needs of renewable energy actors.	2016	Renewable and Sustainable Energy Reviews
Mignon I, Bergek A. Investments in renewable electricity production: the importance of policy revisited.	2016	Renewable Energy

Mitchell C, Bauknecht D, Connor PM. Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany.	2006	Energy Policy
Mitchell C, Connor P. Renewable energy policy in the UK 1990–2003.	2004	Energy Policy
Mora D, Islam M, Soysal ER, Kitzing L, Blanco ALA, Forster S, et al. Experiences with auctions for renewable energy support.	2017	Other: Presented at 14th International Conference on the European Energy Market (EEM)
Morano, P.; Tajani, F.; Locurcio, M. GIS application and econometric analysis for the verification of the financial feasibility of roof-top wind turbines in the city of Bari (Italy).	2017	Renewable and Sustainable Energy Reviews
Motta, M. and Peitz, M. State Aid Policies in Response to the COVID-19 Shock: Observations and Guiding Principles	2020	Intereconomics
Mulder A. Do economic instruments matter? Wind turbine investments in the EU(15).	2008	Energy Economics
Mușatescu, V., Podașcă, C. and Opriș, I. The Romanian state aid policy for promoting electricity produced in high efficiency cogeneration.	2017	European State Aid Law Quarterly (ESTAL)
Nauleau, M.L. Free-riding on tax credits for home insulation in France: An econometric assessment using panel data.	2014	Energy Economics
Nicolaides, P., 2015. A Critical Analysis of Reductions from Environmental Taxes in the New Guidelines on State Aid for Environmental Protection and Energy, 2014–2020.	2015	Energy & Environment
Nicolini M, Tavoni M. Are renewable energy subsidies effective? Evidence from Europe	2017	Renewable and Sustainable Energy Review
Noothout, P., de Jager, D., Tesnière, L., van Rooijen, S., Karypidis, N., Brückmann, R., Jirouš, F., Breitschopf, B., Angelopoulos, D., Doukas, H. and Konstantinavičiūtė, I. The impact of risks in renewable energy investments and the role of smart policies.	2016	DiaCore Report
Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., Batzios, A. and Katsarou, A.. Renewable energy and economic growth: Evidence from European countries.	2018	Sustainability
Ogunlana, A.O. and Goryunova, N.N. Tax Incentives for Renewable Energy: The European Experience.	2017	The European Proceedings of Social & Behavioural Sciences
Olsthoorn, M., Schleich, J., Gassmann, X. and Faure, C.Free riding and rebates for residential energy efficiency upgrades: A multi-country contingent valuation experiment.	2017	Energy Economics
Papież, M., Śmiech, S. and Frodyma, K. Determinants of renewable energy development in the EU countries. A 20-year perspective.	2018	Renewable and Sustainable Energy Reviews
Peña I, Azevedo I, Marcelino Ferreira LAF. Lessons from wind policy in Portugal.	2017	Energy Policy
Polzin F, Egli F, Steffen B, Schmidt TS. How do polices mobilize private finance for renewable energy? – A systematic review with investor perspective	2019	Applied Energy
Polzin F, Migendt M, Täube FA, von Flotow P. Public policy influence on renewable energy investments-a panel data study across OECD countries.	2015	Energy Policy

Punda, L., Capuder, T., Pandžić, H. and Delimar, M. Integration of renewable energy sources in southeast Europe: A review of incentive mechanisms and feasibility of investments.	2017	Renewable and Sustainable Energy Reviews
PWC, Report for Invest NL. Financing Offshore Wind.	2020	Government Reports and Commissioned Studies
Quintana-Rojo, C., Callejas-Albiñana, F.E., Tarancón, M.Á. and Martínez-Rodríguez, I. Econometric Studies on the Development of Renewable Energy Sources to Support the European Union 2020–2030 Climate and Energy Framework: A Critical Appraisal.	2020	Sustainability
Ragwitz, M., Held A., Sensfuss F., Huber C., Resch G., Faber T ., et al.OPTRES—assessment and optimisation of renewable support schemes	2006	Intelligent Energy Europe
Righini, E. and De Gasperi, G.C., 2019. Survey–the application of EU State aid law in the energy sector.	2019	Journal of European Competition Law & Practice
Robins, N. and Chakma, T., 2016. State Aid in Energy under the Spotlight.	2016	European State Aid Law Quarterly
Rodríguez M, Haščič I, Johnstone N, Silva J, Ferey A. Renewable energy policies and private sector investment: evidence from Financial Microdata.	2015	Environmental and Resource Economics
Romano AA, Scandurra G, Carfora A, Fodor M. Renewable investments: the impact of green policies in developing and developed countries.	2017	Renewable and Sustainable Energy Review
Romano, T., Mennel, T. and Scatasta, S Comparing feed-in tariffs and renewable obligation certificates: the case of repowering wind farms.	2017	Economia e Politica Industriale
Rüdinger, A. Éléments d'analyse pour une stratégie de déploiement et d'intégration des énergies renouvelables électriques en France.	2016	IDDRI Working Paper
Sánchez-Braza, A. and Pablo-Romero, M.D.P.Evaluation of property tax bonus to promote solar thermal systems in Andalusia (Spain).	2014	Energy Policy
Schallenberg-Rodriguez, J. Renewable electricity support systems: Are feed-in systems taking the lead?.	2017	Renewable and Sustainable Energy Reviews
Schallenberg-Rodriguez J, Haas R. Fixed feed-in tariff versus premium: a review of the current Spanish system.	2012	Renewable and Sustainable Energy Review
Schmidt TS, Schneider M, Hoffmann VH. Decarbonising the power sector via technological change – differing contributions from heterogeneous firms.	2012	Energy Policy
Schmidt TS, Schneider M, Rogge KS, Schuetz MJA, Hoffmann VH. The effects of climate policy on the rate and direction of innovation: a survey of the EU ETS and the electricity sector.	2012	Environmental Innovation and Societal Transitions
Sebi, Carine, and Anne-Lorène Vernay. "Community renewable energy in France: The state of development and the way forward."	2020	Energy Policy
Sedláčková, A.N. and Švecová, D. Do the Slovak Airports need the State Economic Framework for Financial Support?	2019	Transportation Research Procedia
Sequeira, T.N. and Santos, M.S. Renewable energy and politics: A systematic review and new evidence.	2018	Journal of Cleaner Production
Shivakumar, A., Dobbins, A., Fahl, U. and Singh, A. Drivers of renewable energy deployment in the EU: An analysis of past trends and projections.	2019	Energy Strategy Reviews

Smith MG, Urpelainen J. The effect of feed-in tariffs on renewable electricity generation: an instrumental variables approach.	2013	Environmental and Resource Economics
Sneum, D.M., Sandberg, E., Koduvere, H., Olsen, O.J. and Blumberga, Policy incentives for flexible district heating in the Baltic countries.	2018	Utilities Policy
Sokołowski, Maciej M. European Law on Combined Heat and Power.	2020	Book, Routledge
Sołtysik, M. and Mucha-Kuś, K. Influence of Regulations on Market Efficiency from the Viewpoint of High-efficiency Cogeneration.	2014	Acta Energetica
Sovacool BK. The importance of comprehensiveness in renewable electricity and energy-efficiency policy.	2009	Energy Policy
Steffen B, Egli F, Pahle M, Schmidt TS. Navigating the Clean Energy Transition in the COVID-19 Crisis	2020	Joule
Stoltmann, A., Jaskólski, M. and Bućko, P. Optimization of combined heat and power (CHP) market allocation: The case of Poland.	2019	IOP conference proceedings
Swedish National Audit Office. Klimatklivet: Support for Local Climate Investments	2019	Government Reports and Commissioned Studies
Szabó, L., Kelemen, Á., Mezősi, A., Pató, Z., Kácsor, E., Resch, G. and Liebmann, L. South East Europe electricity roadmap–modelling energy transition in the electricity sectors.	2019	Climate policy
Uslu, A. Effects of policy framework in the bioenergy market.	2016	Biomass Policies (Intelligent Energy for Europe)
Van Hees S. Investment State Aid for Ocean Energy Projects in the EU: A Lack of Integration with the Renewable Energy Directive.	2018	European State Aid Law Quarterly
Voica, M.C. and Panait, M. Challenges Imposed by Renewable Energy Paradigms of the Romanian Economy from the European Perspective.	2019	Economic Insights Trends Challenges
Vollebergh,H. Planbureau voor de Leeformgeving, De Energie - Investeringsaftrek: Freeriding Binnin de perken (The energy investment allowance: freeriding within limits)	2020	Government Reports and Commissioned Studies
Wall R, Grafakos S, Gianoli A, Stavropoulos S. Which policy instruments attract foreign direct investments in renewable energy?	2018	Climate Policy
Wędzik, A., Siewierski, T. and Szypowski, M. Green certificates market in Poland–The sources of crisis.	2017	Renewable and Sustainable Energy Reviews
Westner, G. and Madlener, R. The benefit of regional diversification of cogeneration investments in Europe: A mean-variance portfolio analysis.	2010	Energy Policy
Winkler J, Magosch M, Ragwitz M. Effectiveness and efficiency of auctions for supporting renewable electricity – what can we learn from recent experiences?	2018	Renewable Energy
Wohlgemuth N, and Madlener R. "Financial support of renewable energy systems: investment vs operating cost subsidies	2000	NAEE Conference Proceedings: Towards an Integrated European Energy Market"
Woodman B, Mitchell C. Learning from experience? The development of the Renewables Obligation in England and Wales 2002–2010.	2011	Energy Policy

Yan S, The economic and environmental impacts of tax incentives for battery electric vehicles in Europe	2018	Energy Policy
Zhong, H., Tan, Z., He, Y., Xie, L. and Kang, C. Implications of COVID-19 for the electricity industry: A comprehensive review.	2020	Journal of Power and Energy Systems
Zhou, S., Matisoff, D.C., Kingsley, G.A. and Brown, M.A. Understanding renewable energy policy adoption and evolution in Europe: The impact of coercion, normative emulation, competition, and learning.	2019	Energy Research & Social Science
Zuidema, L. State aid for solid biomass: the case for improved scrutiny.	2020	Cadmus Research Repository (Working Paper)

Source: UEA.

Annex 7 Tabular review of the policy influence of investment aid and operating aid policy instruments on renewable energy and environmental protection policy

Table 41: Tabular review of the policy influence of investment aid and operating aid policy instruments on renewable energy and environmental protection policy

Source	Tech. Scope	Quantitative/Qualitative	Feed-In Tariff	Feed-in Premium	Auction	Tax Credit	Grant	Loan	Investment Tax Credit	Guarantee	Green Certificate Scheme	Direct Investment
Aceleanu, M.I., Şerban, A.C., Pociovălişteanu, D.M. and Dimian, G.C. Renewable energy: A way for a sustainable development in Romania.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
Adamczyk J, and Graczyk M. "Green certificates as an instrument to support renewable energy in Poland—Strengths and weaknesses."	RES	Qualitative	-	-	-	-	-	-	-	-	YN	-
Adigbli, P. and Mahuet, A. The impact of intermittent sources of energy on the market price of electricity.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-
Aguirre M, Ibikunle G. Determinants of renewable energy growth: a global sample analysis.	RES	Quantitative	Y	U	U	N	N	U	U	U	U	U
Ahmadov, A.K. and van der Borg, C. Do natural resources impede renewable energy production in the EU? A mixed-methods analysis.	RES	Quantitative	Y	-	-	Y	Y	-	-	-	-	-
Allen, M.L., Allen, M.M., Cumming, D. and Johan, S. Comparative Capitalisms and Energy Transitions: Renewable Energy in the European Union.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Alola, A.A., Yalçiner, K., Alola, U.V. and Saint Akadiri, S. The role of renewable en-	RES	Qualitative	-	-	-	-	-	-	-	-	-	-

ergy, immigration and real income in environmental sustainability target. Evidence from Europe largest states.												
Alolo, M. and Azevedo, A. The effect of the feed-in-system policy on renewable energy investments: Evidence from the EU countries.	RES	Quantitative	Y (but design important)	Y (but design important)	-	-	-	-	-	-	-	-
Andor, M. and Voss, A. Optimal renewable-energy promotion: Capacity subsidies vs. generation subsidies.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Ang G, Röttgers D, Burli P. The empirics of enabling investment and innovation in renewable energy. OECD Environ Work Pap.	RES	Quantitative	Y	U	U	-	-	-	-	-	U	-
	Wind	Quantitative	U	U	Y	-	-	-	-	-	Y	-
	PV	Quantitative	Y	U	U	-	-	-	-	-	Y	-
Angelopoulos, D., Brückmann, R., Jirouš, F., Konstantinavičiūtė, I., Noothout, P., Psarras, J., Tesnière, L. and Breitschopf, B. Risks and cost of capital for onshore wind energy investments in EU countries.	Wind	Qualitative	-	-	-	-	-	-	-	-	-	-
Angelopoulos, D., Doukas, H., Psarras, J. and Stamtsis, G.Risk-based analysis and policy implications for renewable energy investments in Greece.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Aranda-Usón, A.; Portillo-Tarragona, P.; Marín-Vinuesa, L.M.; Scarpellini, S. Financial resources for the circular economy: A perspective from businesses.	Other	Qualitative	-	-	-	-	-	-	-	-	-	-
Baldwin E, Carley S, Brass JN, Maclean LM. Global renewable electricity policy: a comparative policy analysis of countries by income status.	RES	Quantitative	Y	-	-	-	Y	-	-	-	-	-

Baltputnis, K., Broka, Z. and Sauhats, A. Assessing the Value of Subsidizing Large CHP Plants.	CHP	Quantitative	-	-	-	-	-	-	-	-	-	-
Banja, M., Jégard, M., Motola, V. and Sikkema, R. Support for biogas in the EU electricity sector–A comparative analysis.	Biogas	Qualitative	-	-	-	-	-	-	-	-	-	-
Barreiro Carril, M.C., Spanish Tax Credit for Investments in Environmental Protection: An Example of a Tax Incentive Compatible with EU Rules on State Aid.	Environmental Protection	Qualitative	-	-	-	-	-	-	-	-	-	-
Barton, B., P Schutte. Electric vehicle law and policy: a comparative analysis	Low Emission Mobility	Qualitative	-	-	-	YN	YN	-	-	-	-	-
Bellantuono, G.The misguided quest for regulatory stability in the renewable energy sector.	RES		Y	Y	-	-	-	-	-	-	Y	-
Bersalli, G., Menanteau, P. and El-Methni, J. Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America.	RES	Quantitative	Y	-	Y	-	-	-	-	-	Y	-
Bergek A, Jacobsson S. Are tradable green certificates a cost-efficient policy driving technical change or a rent-generating machine? Lessons from Sweden 2003–2008.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Best R, Burke PJ. Adoption of solar and wind energy: the roles of carbon pricing and aggregate policy support.	Solar PV	Quantitative	Y	-	-	-	-	-	-	-	-	-
	Solar Thermal	Quantitative	Y	-	-	-	-	-	-	-	-	-
	Wind	Quantitative	-	-	-	-	-	-	-	-	N	-

Blom, M., Vergeer, R., Wielders, L., Schep, E., Hof, B., Buunk, E. and Tieben, B. Evaluatie van de SDE+-regeling.	RES	Qualitative	Y	Y	-	-	-	-	-	-	-	-
Boehringer, C.; Cuntz, A.N.; Harhoff, D.; Asane-Otoo, E. The Impacts of Feed-in Tariffs on Innovation: Empirical Evidence from Germany	RES	Quantitative	Y (however no effect on innovation)	-	-	-	-	-	-	-	-	-
Bolkesjoe TF, Eltvig PT, Nygaard E. An econometric analysis of support scheme effects on renewable energy investments in Europe.	Wind	Quantitative	Y	-	U	-	-	-	-	-	-	-
	PV	Quantitative	Y	-	U	-	-	-	-	-	-	-
	Bio-Energy	Quantitative	U	-	U	-	-	-	-	-	-	-
Botta, E. An experimental approach to climate finance: the impact of auction design and policy uncertainty on renewable energy equity costs in Europe.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Bougette, P. and Charlier, C.La difficile conciliation entre politique de concurrence et politique industrielle: le soutien aux énergies renouvelables.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
Buckman G. The effectiveness of Renewable Portfolio Standard banding and carve-outs in supporting high-cost types of renewable electricity.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Butler L, Neuhoff K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development.	Wind	Qualitative	Y	-	U	-	-	-	-	-	-	-
Brijs, T., De Vos, K., De Jonghe, C. and Belmans, R., Statistical analysis of negative prices in European balancing markets.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-

Broin, E.Ó., Nässén, J. and Johnsson, F. Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010.	Energy Effi-ciency	Quantita-tive	-	-	-	-	-	-	-	-	-	-
Cansino JM, Pablo-Romero M del P, Román R, Yñiguez R. Tax incentives to promote green electricity: an overview of EU-27 countries.	RES	Qualita-tive	-	-	-	U	-	-	U	-	-	-
Carley S, Baldwin E, MacLean LM, Brass JN. Global expansion of renewable energy generation: an analysis of policy instruments.	RES	Quantita-tive	Y*	-	-	-	U	-	-	-	-	-
Ćetković, S. and Buzogány, A. Varieties of capitalism and clean energy transitions in the European Union: When renewable energy hits different economic logics.	RES	Qualita-tive	Y	-	-	-	-	-	-	-	-	-
Charlier, D. Energy efficiency investments in the context of split incentives among French households.	Energy Effi-ciency	Quantita-tive	-	-	-	N	-	-	-	-	-	-
Choi H, Anadón LD. The role of the complementary sector and its relationship with network formation and government policies in emerging sectors: the case of solar photovoltaics between 2001 and 2009.	PV	Quantita-tive	Y	-	-	-	-	-	-	-	-	-
Christensen, J.L. and Hain, D.S.Knowing where to go: The knowledge foundation for investments in renewable energy.	RES	Qualita-tive	-	-	-	-	-	-	-	-	-	-
Chyong, C., Pollitt, M. and Cruise, R. Can wholesale electricity prices support "subsidy-free" generation investment in Europe?.	RES	Quantita-tive	-	-	-	-	-	-	-	-	-	-
Cludius, J., Hermann, H., Matthes, F.C. and Graichen, V.The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications.	RES	Quantita-tive	-	-	-	-	-	-	-	-	-	-

Criscuolo C, Menon C. Environmental policies and risk finance in the green sector: cross-country evidence.	RES	Quantitative	U	Y	-	-	-	-	-	-	U	-
	Wind	Quantitative	Y	Y	-	-	-	-	-	-	U	-
	PV	Quantitative	Y N	Y	-	-	-	-	-	-	U	-
Cumming D, Henriques I, Sadorsky P. "Cleantech" venture capital around the world.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Del Río, P. The dynamic efficiency of feed-in tariffs: The impact of different design elements.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
del Río P, Gual MA. An integrated assessment of the feed-in tariff system in Spain.	RES	Qualitative	U	U	-	-	-	-	-	-	-	-
	Hydro	Qualitative	-	-	-	-	-	-	-	-	-	-
del Río P, Linares P. Back to the future? Rethinking auctions for renewable electricity support.	RES	Qualitative	-	-	Y*	-	-	-	-	-	-	-
del Río P, Tarancón MA. Analysing the determinants of on-shore wind capacity additions in the EU: an econometric study.	Wind	Quantitative	Y	-	-	-	-	-	-	-	-	-
del Río P, Unruh G. Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity.	Wind	Qualitative	U	U	-	-	-	-	-	-	-	-
	PV	Qualitative	Y	U	-	-	-	-	-	-	-	-
De Vos, K. Negative wholesale electricity prices in the German, French and Belgian day-ahead, intra-day and real-time markets.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-
Deller, D., Ennis, S., Enstone, B., Głowicka, E., Hofmann M., Mäkelä, P., Snaith, G., and Witte, S. Retrospective evaluation support study on State aid rules for environmental protection and energy.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-

Dijkgraaf E, van Dorp TP, Maasland E. On the effectiveness of feed-in tariffs in the development of photovoltaic solar.	PV	Quantitative	Y	-	-	-	-	-	-	-	-	-
Dincer, H., Yüksel, S. and Martinez, L. Balanced scorecard-based Analysis about European Energy Investment Policies: A hybrid hesitant fuzzy decision-making approach with Quality Function Deployment.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Dong CG. Feed-in tariff vs. renewable portfolio standard: an empirical test of their relative effectiveness in promoting wind capacity development.	Wind	Quantitative	Y	-	-	-	-	-	-	-	-	-
Duruisseau, K. The development of ground-based photovoltaic power plants in the territories of southern France State of play, factors and territorialization.	PV	Qualitative	-	-	-	-	-	-	-	-	-	-
Egli, F. Renewable energy investment risk: An investigation of changes over time and the underlying drivers.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Eleftheriadis IM, Anagnostopoulou EG. Identifying barriers in the diffusion of renewable energy sources.	Wind	Quantitative	U	-	-	U	-	-	-	-	-	-
	PV	Quantitative	U	-	-	U	-	-	-	-	-	-
Engström, G., Gars, J., Jaakkola, N., Lindahl, T., Spiro, D. and van Benthem, A.A. What policies address both the coronavirus crisis and the climate crisis?	Other	Qualitative	-	-	-	-	-	-	-	-	-	-
European Commission. Renewable Energy Progress Report COM(2020)952	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
European Commission. fifth Report on the state of the energy union COM(2020)950 (including annex reports, progress report	RES	Quantitative	-	-	-	-	-	-	-	-	-	-

on the internal energy market and Energy subsides in the EU												
European Commission. fifth Report on the state of the energy union: Progress report on competitiveness COM(2020)953	Environmental Protection	Qualitative	-	-	-	-	-	-	-	-	-	-
European Commission. In-Depth Analysis in Support of the commission communication com (2018) 773: A Clean Planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy	Environmental Protection	Quantitative	-	-	-	-	-	-	-	-	-	-
Eyraud L, Clements B, Wane A. Green investment: Trends and determinants.	RES	Quantitative	Y	-	-	-	-	-	-	-	-	-
Fouquet D, Johansson TB. European renewable energy policy at crossroads-focus on electricity support mechanisms.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
García-Álvarez MT, Cabeza-García L, Soares I. Analysis of the promotion of on-shore wind energy in the EU: Feed-in tariff or renewable portfolio standard?	Wind	Quantitative	Y	-	-	-	-	-	-	-	-	-
Gavard C. Carbon price and wind power support in Denmark.	Wind	Quantitative	Y	Y	-	-	-	-	-	-	-	-
Gawel, E. and Lehmann, P. Should renewable energy policy be ‘renewable’?	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Geddes A, Schmidt TS, Steffen B. The multiple roles of state investment banks in low-carbon energy finance: an analysis of Australia, the UK and Germany.	RES	Qualitative	-	-	-	-	-	-	Y*	Y*	-	Y*
Gephart, M., Klessmann, C. and Wigand, F. Renewable energy auctions–When are they (cost-) effective?	RES	Qualitative	-	-	-	-	-	-	-	-	-	-

Gillingham, K., Keyes, A. and Palmer, K. Advances in evaluating energy efficiency policies and programs.	Energy Efficiency	Qualitative	-	-	-	-	-	-	-	-	-	-
Gippner, O. and Torney, D. Shifting policy priorities in EU-China energy relations: Implications for Chinese energy investments in Europe.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Gökgöz, F. and Güvercin, M.T. Energy security and renewable energy efficiency in EU.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Grafström, J.; Lindman, Å. Invention, innovation and diffusion in the European wind power sector.	Wind	Quantitative	Y	-	Y	-	-	-	-	-	-	-
Grösche, P., Schmidt, C.M. and Vance, C. Identifying free-riding in home-renovation programs using revealed preference data.	Energy Efficiency	Quantitative	-	-	-	-	N	-	-	-	-	-
Gürtler, K., Postpischil, R. and Quitzow, R. The dismantling of renewable energy policies: The cases of Spain and the Czech Republic.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
Gutermuth PG. Financial measures by the state for the enhanced deployment of renewable energies.	Wind	Qualitative	U	Y	-	-	U	Y	U	U	-	-
	PV	Qualitative	U	Y*	-	-	Y	U	U	U	-	-
	Bio	Qualitative	U	Y*	-	-	Y	Y	Y*	U	-	-
	Geo	Qualitative	U	U	-	-	U	Y	U	U	-	-
	Hydro	Qualitative	U	Y	-	-	U	Y	Y	U	-	-
Haas R, Panzer C, Resch G, Ragwitz M, Reece G, Held A. A historical review of promotion strategies for electricity from renewable energy sources in EU countries.	RES	Qualitative	Y	-	Y*	Y*	-	Y*	-	-	-	-

Hansen, K., Mathiesen, B.V. and Skov, I.R. Full energy system transition towards 100% renewable energy in Germany in 2050.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Heiskanen E, Jalas M, Juntunen JK, Nissilä H. Small streams, diverse sources: who invests in renewable energy in Finland during the financial downturn?	Wind	Qualitative	Y	-	-	-	-	-	-	-	-	-
	PV	Qualitative	U	-	-	-	-	-	-	-	-	-
	Bio	Qualitative	U	-	-	-	-	-	-	-	-	-
	Geothermal	Qualitative	U	-	-	-	-	-	-	-	-	-
	Other	Qualitative	U	-	-	-	-	-	-	-	-	-
Hitaj, C.; Löschel, A. The Impact of a Feed-In Tariff on Wind Power Development in Germany.	Wind	Quantitative	Y	-	-	-	-	-	-	-	-	-
Höckner, J., Voswinkel, S. and Weber, C. Market distortions in flexibility markets caused by renewable subsidies	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Hu, J., Harmsen, R., Crijns-Graus, W. Worrell, E and van den Broek, M. Identifying barriers to large-scale integration of variable renewable electricity into the electricity market: A literature review of market design.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Huntington, S.C., Rodilla, P., Herrero, I. and Batlle, C. Revisiting support policies for RES-E adulthood: Towards market compatible schemes.	RES	Qualitative	Y	Y	-	-	-	-	-	-	-	-
Inês, C., Guilherme, P.L., Esther, M.G., Swantje, G., Stephen, H. and Lars, H. Regulatory challenges and opportunities for collective renewable energy prosumers in the EU.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-

Isberg, U., Jonsson, L., Pädam, S., Hallberg, A., Nilsson, M. and Malmström, C., 2017. Klimatklivet–en utvärdering av styrmedlets effekter.	RES	Qualitative	-	-	-	-	Y	-	-	-	-	-
Iychettira, K.K., Hakvoort, R.A. and Linares, P. Towards a comprehensive policy for electricity from renewable energy: An approach for policy design.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Jääskeläincn, J., Huhta, K. and Lehtomäki, J. Ensuring generation adequacy in Finland with smart energy policy-How to save Finnish CHP production?	CHP	Mixed Methods	Y N	-	-	-	-	-	-	-	-	-
Jacobsson S, Lauber V. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology.	RES	Qualitative	U	U	-	-	-	-	-	-	-	-
Jenner S, Groba F, Indvik J. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries.	Wind	Quantitative	Y	U	U	U	U	-	-	-	-	-
	PV	Quantitative	Y	U	U	U	U	-	-	-	-	-
Johnstone N, Haščič I, Popp D. Renewable energy policies and technological innovation: evidence based on patent counts.	RES	Quantitative	U	-	-	U	Y	Y	Y	Y	U	-
	Wind	Quantitative	N	-	-	U	U	U	U	U	U	-
	PV	Quantitative	Y	-	-	U	U	U	U	U	U	-
	Bio	Quantitative	U	-	-	U	Y	Y	Y	Y	U	-
	Geothermal	Quantitative	U	-	-	U	Y	Y	Y	Y	U	-
	Marine	Quantitative	U	-	-	U	U	U	U	U	U	-

Kelsey, N. and Meckling, J. Who wins in renewable energy? Evidence from Europe and the United States.	Wind	Quantitative	YN	-	-	-	-	-	-	-	-	-
	Solar	Quantitative	YN	-	-	-	-	-	-	-	-	-
Kester, J., Noel, L., de Rubens G.E., Sovacool B.K. Policy mechanisms to accelerate electric vehicle adoption: a qualitative review from the Nordic region	Low Emission Mobility	Qualitative	-	-	-	-	-	-	-	-	-	-
Kilinc-Ata N. The evaluation of renewable energy policies across EU countries and US states: an econometric approach.	RES	Quantitative	Y	-	Y	Y	-	-	-	-	-	-
Kim J, Park K. Financial development and deployment of renewable energy technologies.	RES	Quantitative	Y	-	-	-	-	-	-	-	Y	-
Kim, K.; Heo, E.; Kim, Y. Dynamic Policy Impacts on a Technological-Change System of Renewable Energy: An Empirical Analysis.	Wind	Quantitative	Y	-	-	-	-	-	-	-	-	-
	Solar	Quantitative	Y	-	-	-	-	-	-	-	-	-
Kim, K.; Kim, Y. Role of policy in innovation and international trade of renewable energy technology: Empirical study of solar PV and wind power technology.	Wind	Quantitative	-	-	-	-	-	-	-	-	-	-
	Solar	Quantitative	-	-	-	-	-	-	-	-	-	-
Kitzing, L., Islam, M. and Fitch-Roy, O. Comparison of auctions and alternative policy options for RES-E support.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Lauber V. REFIT and RPS: Options for a harmonised Community framework.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
Leete S, Xu J, Wheeler D. Investment barriers and incentives for marine renewable energy in the UK: an analysis of investor preferences.	Marine	Qualitative	-	-	-	-	-	-	-	-	-	-

Lévay, P.Z., Drossinos, Y. and Thiel, C. The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership	Low Emission Mobility	Quantitative	-	-	-	YN	YN	-	-	-	-	-
Li S-J, Chang T-H, Chang S-L. The policy effectiveness of economic instruments for the photovoltaic and wind power development in the European Union.	Wind	Quantitative	Y	-	-	Y	Y	Y	-	-	-	-
	PV	Quantitative	Y	-	-	U	U	U	-	-	-	-
Linnerud K, Holden E. Investment barriers under a renewable-electricity support scheme: differences across investor types.	Hydro	Quantitative	-	-	-	-	-	-	-	-	-	U
	Hydro	Quantitative	-	-	-	-	-	-	-	-	-	U
Lipp J. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-
Liu, W., Zhang, X. and Feng, S. Does renewable energy policy work? Evidence from a panel data analysis.	RES	Quantitative	Y	Y	Y	N	Y	-	N	-	YN	-
Maillo, J. Balancing Environmental Protection, Competitiveness and Competition: A Critical Assessment of the GBER and EEAG.	Environmental Protection	Qualitative	-	-	-	-	-	-	-	-	-	-
Marinaș, M.C., Dinu, M., Socol, A.G. and Socol, C. Renewable energy consumption and economic growth. Causality relationship in Central and Eastern European countries.	RES	Quantitative	-	-	-	-	-	-	-	-	Y	-
Marques AC, Fuinhas JA. Are public policies towards renewables successful? Evidence from European countries.	RES	Quantitative	Y	Y	Y	Y	Y	Y	Y	Y	-	-
Marques AC, Fuinhas JA. Do energy efficiency measures promote the use of renewable sources?	RES	Quantitative	-	-	-	-	-	-	-	-	-	-

Marques, A.C., Fuinhas, J.A. and Pereira, D.S.The dynamics of the short and long-run effects of public policies supporting renewable energy: A comparative study of installed capacity and electricity generation.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Matthäus, D. and Mehling, M. De-risking Renewable Energy Investments in Developing Countries: A Multilateral Guarantee Mechanism.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Mazzucato, M. and Semieniuk, G. Financing renewable energy: Who is financing what and why it matters.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Menanteau P, Finon D, Lamy ML. Prices versus quantities: Choosing policies for promoting the development of renewable energy.	Wind	Qualitative	Y	-	-	-	-	-	-	-	-	-
Mezősi, A., Kácsor, E., Beöthy, Á., Törőcsik, Á. and Szabó, L. Modelling support policies and renewable energy sources deployment in the Hungarian district heating sector.	CHP	Quantitative	Y	-	-	N	Y	-	-	-	-	-
Michalena, E. and Hills, J.M. Stepping up but back: How EU policy reform fails to meet the needs of renewable energy actors.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Mignon I, Bergek A. Investments in renewable electricity production: the importance of policy revisited.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Mitchell C, Bauknecht D, Connor PM. Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany.	RES	Qualitative	Y	Y	-	-	-	-	-	-	-	-
Mitchell C, Connor P. Renewable energy policy in the UK 1990–2003.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-

Mora D, Islam M, Soysal ER, Kitzing L, Blanco ALA, Forster S, et al. Experiences with auctions for renewable energy support.	RES	Qualitative	-	Y*	-	-	-	-	-	-	-	-
Morano, P.; Tajani, F.; Locurcio, M. GIS application and econometric analysis for the verification of the financial feasibility of roof-top wind turbines in the city of Bari (Italy).	RES	Quantitative	Y*	-	-	-	-	-	-	-	-	-
Motta, M. and Peitz, M. State Aid Policies in Response to the COVID-19 Shock: Observations and Guiding Principles.	Other	Qualitative	-	-	-	-	-	-	-	-	-	-
Mulder A. Do economic instruments matter? Wind turbine investments in the EU (15).	Wind	Quantitative	Y	-	-	Y	Y	Y	-	-	-	-
Mușatescu, V., Podașcă, C. and Opriș, I. The Romanian state aid policy for promoting electricity produced in high efficiency cogeneration.	RES											
Nauleau, M.L. Free-riding on tax credits for home insulation in France: An econometric assessment using panel data.	Energy Efficiency	Quantitative	-	-	-	Y	-	-	-	-	-	-
Nicolaides, P. A Critical Analysis of Reductions from Environmental Taxes in the New Guidelines on State Aid for Environmental Protection and Energy, 2014–2020.	Energy Intensive Users	Quantitative	-	-	-	-	-	-	-	-	-	-
Nicolini M, Tavoni M. Are renewable energy subsidies effective? Evidence from Europe.	RES	Quantitative	Y	-	-	-	-	-	-	-	N	-
	Hydro	Quantitative	-	-	-	-	-	-	-	-	-	-
Noothout, P., de Jager, D., Tesnière, L., van Rooijen, S., Karypidis, N., Brückmann, R., Jirouš, F., Breitschopf, B., Angelopoulos, D., Doukas, H. and Konstantinavičiūtė, I. The impact of risks in renewable energy investments and the role of smart policies.	Wind	Quantitative	-	-	-	-	-	-	-	-	-	-

Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., Batzios, A. and Katsarou, A. Renewable energy and economic growth: Evidence from European countries.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Ogunlana, A.O. and Goryunova, N.N. Tax Incentives for Renewable Energy: The European Experience.	Wind	Qualitative	-	-	-	Y	-	-	-	-	-	-
Olsthoorn, M., Schleich, J., Gassmann, X. and Faure, C. Free riding and rebates for residential energy efficiency upgrades: A multi-country contingent valuation experiment.	Energy Efficiency	Quantitative	-	-	-	-	-	-	-	-	-	-
Papież, M., Śmiech, S. and Frodyma, K. Determinants of renewable energy development in the EU countries. A 20-year perspective.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Peña I, Azevedo I, Marcelino Ferreira LAF. Lessons from wind policy in Portugal.	Wind	Qualitative	Y*	-	-	-	-	-	-	-	-	-
Polzin F, Migendt M, Täube FA, von Flotow P. Public policy influence on renewable energy investments-a panel data study across OECD countries.	RES	Quantitative	Y	-	-	Y	U	U	U	U	U	N
	Wind	Quantitative	Y	-	-	U	U	U	U	U	U	U
	PV	Quantitative	Y	-	-	Y	Y	N	U	U	N	N
	Bio-Energy	Quantitative	U	-	-	U	U	U	U	U	U	Y N
Polzin, F., Egli, F., Steffen, B. and Schmidt, T.S. How do policies mobilize private finance for renewable energy? —A systematic review with an investor perspective.	RES	Quantitative	Y	Y	Y	Y	YN	YN	YN	YN	Y	YN
Punda, L., Capuder, T., Pandžić, H. and Delimar, M. Integration of renewable energy sources in southeast Europe: A review of incentive mechanisms and feasibility of investments.	RES	Qualitative	Y	-	-	-	-	-	-	-	-	-

PWC. Financing Offshore Wind: A study commissioned by Invest-NL	Wind	Quantitative	-	-	-	-	-	-	-	-	-	-
Quintana-Rojo, C., Callejas-Albiñana, F.E., Tarancón, M.Á. and Martínez-Rodríguez, I. Econometric Studies on the Development of Renewable Energy Sources to Support the European Union 2020–2030 Climate and Energy Framework: A Critical Appraisal.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Ragwitz, M., Held A., Sensfuss F., Huber C., Resch G., Faber T ., et al.OPTRES—assessment and optimisation of renewable support schemes in the European electricity market	Wind, Biogas,PV	Quantitative	Y									
	Sewage Gas, Solid Biomass	Quantitative				Y					Y	
Righini, E. and De Gasperi, G.C. Survey–the application of EU State aid law in the energy sector.	Energy	Qualitative	-	-	-	-	-	-	-	-	-	-
Robins, N. and Chakma, T. State Aid in Energy under the Spotlight.	Energy	Qualitative	-	-	-	-	-	-	-	-	-	-
Rodríguez MC, Haščič I, Johnstone N, Silva J, Ferey A. Renewable energy policies and private sector investment: evidence from Financial Microdata.	RES	Quantitative	Y N	-	-	Y N	-	-	-	-	-	-
	Wind	Quantitative	Y*	-	-	Y*	-	-	-	-	-	-
	PV	Quantitative	Y*	-	-	U	-	-	-	-	-	-
	Bio-Energy	Quantitative	Y	-	-	Y*	-	-	-	-	-	-

	Hydro	Quantitative	N	-	-	U	-	-	-	-	-	-
Romano AA, Scandurra G, Carfora A, Fodor M. Renewable investments: the impact of green policies in developing and developed countries.	RES	Quantitative	N	-	-	Y	U	U	Y	-	Y	U
Romano, T., Mennel, T. and Scatasta, S Comparing feed-in tariffs and renewable obligation certificates: the case of repowering wind farms.	RES	Quantitative	Y	-	-	-	-	-	-	-	N	-
Rüdinger, A. Éléments d'analyse pour une stratégie de déploiement et d'intégration des énergies renouvelables électriques en France.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Sánchez-Braza, A. and Pablo-Romero, M.D.P.Evaluation of property tax bonus to promote solar thermal systems in Andalusia (Spain).	Solar	Quantitative	-	-	-	Y	-	-	-	-	-	-
Schallenberg-Rodriguez J, Haas R. Fixed feed-in tariff versus premium: a review of the current Spanish system.	RES	Qualitative	Y N	Y N	-	-	-	-	-	-	-	-
Schallenberg-Rodriguez, J. Renewable electricity support systems: Are feed-in systems taking the lead?	RES	Qualitative	Y	Y	-	-	-	-	-	-	N	-
Schmidt TS, Schneider M, Hoffmann VH. Decarbonising the power sector via technological change – differing contributions from heterogeneous firms.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-
Schmidt TS, Schneider M, Rogge KS, Schuetz MJA, Hoffmann VH. The effects of climate policy on the rate and direction of innovation: a survey of the EU ETS and the electricity sector.	Other	Quantitative	-	-	-	-	-	-	-	-	-	-
Sebi, Carine, and Anne-Lorène Vernay. "Community renewable energy in France:	RES	Qualitative	Y	-	-	-	Y	-	-	-	-	-

The state of development and the way forward."												
Sedláčková, A.N. and Švecová, D. Do the Slovak Airports need the State Economic Framework for Financial Support?	Other	Quantitative	-	-	-	-	-	-	-	-	-	-
Sequeira, T.N. and Santos, M.S. Renewable energy and politics: A systematic review and new evidence.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Shivakumar, A., Dobbins, A., Fahl, U. and Singh, A. Drivers of renewable energy deployment in the EU: An analysis of past trends and projections.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Smith MG, Urpelainen J. The effect of feed-in tariffs on renewable electricity generation: an instrumental variables approach.	RES	Quantitative	Y	-	-	-	-	-	-	-	-	-
Sneum, D.M., Sandberg, E., Koduvere, H., Olsen, O.J. and Blumberga, D. Policy incentives for flexible district heating in the Baltic countries.	CHP	Quantitative	-	-	-	N	N	-	N	-	-	-
Sokołowski, M.M. European Law on Combined Heat and Power.	CHP	Qualitative	U	U	U	N	U	U	N	U	U	U
Sołtysik, M. and Mucha-Kuś, K. Influence of Regulations on Market Efficiency from the Viewpoint of High-efficiency Cogeneration.	CHP	Qualitative	-	-	-	-	-	-	-	-	N	-
Sovacool BK. The importance of comprehensiveness in renewable electricity and energy-efficiency policy.	RES	Qualitative	Y	-	-	U	U	U	U	-	-	-
Steffen, B. The importance of project finance for renewable energy projects.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Stoltmann, A., Jaskólski, M. and Bućko, P. Optimization of combined heat and power (CHP) market allocation: The case of Poland.	CHP	Qualitative	-	-	-	-	-	-	-	-	N	-
Swedish National Audit Office. Klimatklivet: Support for Local Climate Investments	RES		-	-	-	-	-	-	-	-	-	-

Szabó, L., Kelemen, Á., Mezősi, A., Pató, Z., Kácsor, E., Resch, G. and Liebmann, L. South East Europe electricity roadmap–modelling energy transition in the electricity sectors.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Uslu, A. Effects of policy framework in the bioenergy market.	Bioenergy	Qualitative	-	-	-	-	YN	-	-	-	Y	-
Van Hees S. Investment State Aid for Ocean Energy Projects in the EU: A Lack of Integration with the Renewable Energy Directive.	Ocean (Tidal, Wave)	Qualitative	-	-	-	-	U	U	U	-	-	-
Voica, M.C. and Panait, M. Challenges Imposed by Renewable Energy Paradigms of the Romanian Economy from the European Perspective.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Vollebergh, H. Planbureau voor de Leeformgeving, De Energie - Investeringsaftrek: Freeriding Binnin de perken (The energy investment allowance: freeriding within limits)	Energy Efficiency	Quantitative	-	-	-	Y	-	-	-	-	-	-
Wall R, Grafakos S, Gianoli A, Stavropoulos S. Which policy instruments attract foreign direct investments in renewable energy?	RES	Quantitative	Y	-	Y	Y	U	-	N	-	U	-
	Wind	Quantitative	Y	-	U	U	U	-	N	-	U	-
	PV	Quantitative	Y	-	Y	U	U	-	Y	-	U	-
	Biomass	Quantitative	Y	-	U	Y	U	-	N	-	N	-
Wędzik, A., Siewierski, T. and Szypowski, M. Green certificates market in Poland–The sources of crisis.	RES	Qualitative	-	-	-	-	-	-	-	-	YN	-
Westner, G. and Madlener, R. The benefit of regional diversification of cogeneration investments in Europe: A mean-variance portfolio analysis.	CHP	Quantitative	-	-	-	-	-	-	-	-	-	-

Winkler J, Magosch M, Ragwitz M. Effectiveness and efficiency of auctions for supporting renewable electricity – what can we learn from recent experiences?	RES	Qualitative	-	Y N	-	-	-	-	-	-	-	-
	Wind	Qualitative	-	Y N	-	-	-	-	-	-	-	-
	PV	Qualitative	-	Y N	-	-	-	-	-	-	-	-
	Biomass	Qualitative	-	Y N	-	-	-	-	-	-	-	-
Wohlgemuth, Norbert, and Reinhard Madlener. "Financial support of renewable energy systems: investment vs operating cost subsidies."	RES	Qualitative	Y N	-	Y	-	Y	-	-	-	Y	-
Woodman B, Mitchell C. Learning from experience? The development of the Renewables Obligation in England and Wales 2002–2010.	RES	Qualitative	-	-	-	-	-	-	-	-	-	-
Yan,S. The economic and environmental impacts of tax incentives for battery electric vehicles in Europe.	Low Emission Mobility	Quantitative	-	-	-	Y	-	-	-	-	-	-
Zhong, H., Tan, Z., He, Y., Xie, L. and Kang, C. Implications of COVID-19 for the electricity industry: A comprehensive review.	Other	Qualitative	-	-	-	-	-	-	-	-	-	-
Zhou, S., Matisoff, D.C., Kingsley, G.A. and Brown, M.A. Understanding renewable energy policy adoption and evolution in Europe: The impact of coercion, normative emulation, competition, and learning.	RES	Quantitative	-	-	-	-	-	-	-	-	-	-
Zuidema, L. State aid for solid biomass: the case for improved scrutiny.	Biomass	Qualitative	-	-	-	-	-	-	-	-	-	-

Source: UEA. Methodology and initial results adopted from Polzin et al 2019 'How to policies mobilize private finance for renewable energy? A systematic review with an investor perspective'.

*Notes: RES=renewable energy scheme, PV= photovoltaic, Y=Positive, N=Negative, U=no instrument effect specified, Y N=mixed evidence, *=paper does not (or sparsely) evaluate policy effects, but discussed design elements, circumstantial effects or other related points in detail.*

Annex 8 Key Elements of Hypothetical Schemes: Carbon Contract for Difference (parameters chosen for study are in bold)

Table 42: Key Elements of Hypothetical Schemes: Carbon Contract for Difference

<table>
<tr><td>Method for establishing contract price for carbon (P)</td><td>Carbon contracts for Difference can be set with a contract price level (P) set by several possible options, of which we choose the last:
▪ at the current EU ETS price level at the time the contract is signed (which could be substantially higher in future years than at the current time due to supply and market fluctuations, and which would be unlikely to deliver decarbonisation at 2020-21 price levels);
▪ above the current EU ETS price level at the time the contract is signed (such as a market derived expected price over contract duration); or
▪ determined by tender (selected option).
If the contract price is established by an administrative process, many of the same problems with the funding gap approach would return (see Annex 9). The tender process is preferred to the first option listed above (linkage to the current EU ETS price), when observers may expect that future prices would not be at that level.</td></tr>
<tr><td>Contract duration</td><td>The contract duration could be short (e.g. 3 years) up to long (e.g. 20 years). We will choose the longer contract duration, 20 years, given the long-run nature of industrial production assets, including CO_2 reduction assets.</td></tr>
<tr><td>Contract volume</td><td>“The contract volume can be dynamic with realised emissions reductions or static (ex-ante).” (ICI, 2020) In principle, it may be desirable to consider indirect as well as direct emissions so that credit for reducing emissions would not accrue to techniques that incorporate inputs with high emissions without counter-balancing those as well. “This [choice between dynamic or static reductions] influences operational incentives, but also financing. In operation, only a dynamic contract volume ensures incentives to deliver emission reductions at the contract price, especially if there are abatement decisions to be made in operation (e.g. in the case of CCS). These would otherwise need to be ensured via additional, complex contract clauses and be monitored. Secondly, in case a risky project does not succeed in achieving its abatement target, no additional clauses are necessary, and neither the public nor the company are exposed to an additional carbon price risk. For the same reason, the contract should cover 100% of emissions reductions, although contracts could in principle only cover a share of emissions reductions.” (ICI, 2020)</td></tr>
<tr><td>Emission scope</td><td>The scope could be defined at level of:
▪ company; or
▪ project (selected option).
The two scopes would be identical when a company is created for the investment. In case CCfDs are treated as an innovation policy, a project-level scope would be necessary so that innovation funding would be directed to innovative processes rather than company-wide abatement.</td></tr>
<tr><td>Contract issuer</td><td>The counter-party is the entity that provides the CCfD and pays when the “project” is out of the money and receives income when it is in the money. Possibilities include:
▪ national governments (selected option);
▪ the European Union and its institutions like the European Investment Bank; or
▪ financial markets.
There is a particularly strong case for financial markets not to originate the CCfD, as unpredictable government policies will strongly influence the appropriate contract price. Note that if government is the counter-party, it can receive funds when the external price is above the contract price. If the</td></tr>
</table>

	financial payments are large, this could create an incentive for governments to manipulate the EU ETS price to generate income from the CCfD.
Eligibility	Which projects or industries will be eligible is a key question. Options include: ▪ only projects that contribute to 2050 goals; ▪ **only industries with high GHG output but subject to GHG reductions exceeding ETS benchmarks (selected option); or** ▪ all sectors. There may be overlap between the first and second option. Opening all sectors to subsidies may have unanticipated (and unsustainably large) financial support requirements. Eligibility is therefore assumed in this case to include cement, steel, fertilisers (ammonia), as well as other key producers of GHG.
Awarding process	The way the funding is awarded would have key impacts on ensuring that the most desirable projects are funded. The awarding process can also have a substantial impact on the role of competition to ensure efficient delivery and avoiding preferential treatment for certain industries over others. Options include: ▪ **Competitive bidding, with projects bidding the CCfD price P (selected option);** ▪ Competitive bidding based on aspects of the project apart from price Eligible bidders could be for all projects within the above eligibility criteria, with a **cross-industry (Option 1)** tender to ensure equal CCfD price across all tenders, ensure competition and equal treatment across industries. If award processes are by **industry (Option 2)**, there is a risk of very few applicants (maybe two in steel, two in cement), and this would be unlikely to work well for a competitive bidding process. The constraint for when awards would not be given could be based on a level of financial risk (for government) entailed by the new and outstanding contracts. If award processes are by country, there may be some that would not have a particular industry present (e.g., steel)

Source: UEA and ICI (2020) at https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/industrial_innovation_part_3_en.pdf.

Annex 9 Key Elements of Hypothetical Schemes: Funding Gap (parameters chosen for study are in bold)

Table 43: Key Elements of Hypothetical Schemes: Funding Gap

Discounted net revenue	**The difference between (a) the sum of discounted revenue and discounted residual value and (b) discounted operating and maintenance costs**
incremental net revenue	The difference between the revenue and the operating costs of two project scenarios ("with the project" and "without the project")
Costs to be taken into account in the calculation of the funding-gap	Running costs (e.g. labour, raw materials, electricity), maintenance expenses and costs for the replacement of project short-life equipment. Financing costs (e.g. interest payments) and depreciation should be excluded (the latter is not a cash-flow).
Contract duration	The contract duration could be short (e.g. 3 years) up to long (e.g. 20 years). Given the long-lived nature of the industrial assets under consideration, we will choose long contract durations that may cover the operational life of the asset, a shorter period that guarantees coverage of the increased capital investment.
Discount rate	A 5% financial discount rate in real terms may be used as indicative benchmark but can be modified in a fair and transparent manner
Emission scope	The scope could be defined at level of:

	▪ company; or ▪ **project (selected option)**. The two scopes would be identical when a company is created for the investment.
Eligibility	Which projects or industries will be eligible is a key question. Options include: ▪ only projects that contribute to 2050 goals; ▪ **only industries with high GHG output but subject to GHG reductions exceeding ETS benchmarks (selected option);** or ▪ all sectors. There may be overlap between the first and second option. Opening all sectors to subsidies may have unanticipated (and unsustainably large) financial support requirements. Eligibility is therefore assumed in this case to include cement, steel, fertilisers (ammonia), as well as other key producers of GHG.

Source: UEA and EC at https://ec.europa.eu/regional_policy/sources/docoffic/cocof/2007/cocof_07_0074_09_en.pdf.

Annex 10 Steel production in the EU

Table 44: Steel production in the EU

EU total (2019) *** ('000,000 tonnes/ year)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BOF & other *	102	102	98	100	103	100	97	99	97	92
EAF *	70	75	70	66	66	65	64	68	69	65
Total Crude steel	173	178	169	166	169	166	162	168	167	158
Consumption of scrap steel *	98	102	95	91	91	90	88	94	90	87
Carbon steel (non alloy) *	138	141	136	134	136	133	128	132	132	125
Carbon steel (other alloy) *	27	29	26	25	25	26	26	28	28	26
Stainless steel *	7.4	7.6	7.4	7.1	7.2	7.2	7.3	7.4	7.4	6.8
Total Crude steel	173	178	169	166	169	166	162	168	167	158

*Source: UEA adapted from https://www.eurofer.eu/assets/Uploads/European-Steel-in-Figures-2020.pdf ** NB: This data includes UK data (UK crude steel production 7,218). Scrap steel is net consumption – there are both imports and exports of scrap steel.*

Annex 11 Cement clinker production for EU 27

Table 45: Cement clinker production for EU 27

Year	Note	Volume (tonnes)
2008	nd	
2009	:E	110,784,443
2010	:E	112,937,004
2011	:E	108,634,688
2012	:E	100,031,465
2013	:R	94,800,793
2014	:	98,318,722
2015	:	104,497,370
2016	:R	112,509,336
2017	:E	119,904,441
2018	:	120,937,296
2019	:	120,901,727

Note:
E = reliable estimate considered accurate enough for constituent Member State volume to be published at the Member State level
R = the data has been rounded using the rounding base given in PROD_QUANTITY_BASE
: = data is not available (i.e. values may be incomplete for this period)
nd = no data

Source: https://ec.europa.eu/eurostat/web/prodcom/data/database DATA FILE: Prodcom Annual Data 2008_ 2019_TD.xlsx.

Annex 12 Fertiliser production for EU 27

Table 46: Fertiliser production for EU 27

Code	Fertiliser	Unit ('000)	Volume (2019)
20151075	Anhydrous ammonia	kg N	11,670,869
20151077	Ammonia in aqueous solution	kg N	508,725
20152030	Ammonium chloride	kg	30,000
20153200	Ammonium sulphate (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg N	2,548,193
20153300	Ammonium nitrate (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg N	3,718,074
20153400	Double salts and mixtures of calcium nitrate and ammonium nitrate (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg N	42,541
20153530	Mixtures of ammonium nitrate with calcium carbonate, ≤ 28 % nitrogen by weight	kg N	2,582,452
20153580	Mixtures of ammonium nitrate with calcium carbonate, > 28 % nitrogen by weight	kg N	600,000
20153600	Mixtures of urea and ammonium nitrate in aqueous or ammoniacal solution (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg N	1,130,089
20153930	Double salts and mixtures of ammonium sulphate and ammonium nitrate (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg N	524,998
20153990	Mineral or chemical fertilisers, nitrogenous, n.e.c.	kg N	1,846,232

20157100	Mineral or chemical fertilisers containing the three fertilising elements nitrogen, phosphorus and potassium (excluding those in tablets or similar forms, or in packages with a gross weight of ≤ 10 kg)	kg	10,645,892
20157200	Diammonium hydrogenorthophosphate (diammonium phosphate) (excluding in tablets or similar forms or in packages of a weight of ≤ 10 kg)	kg	868,822
20157300	Ammonium dihydrogenorthophosphate (monoammonium phosphate)	kg	311,096

Source: https://ec.europa.eu/eurostat/web/prodcom/data/database DATA FILE: Prodcom Annual Data 2008_2019_TD.xlsx.

Annex 13 CO_2 emissions (thousand tonnes) by source sector for EU 27

Table 47: CO_2 emissions (thousand tonnes) by source sector for EU 27

Year	Cement	Iron & Steel	Ammonia	Fertilisers*
Code	CRF2A1	CFR2C1	CRF2B1	
2005	96,083.66	76,458.28	28,355.35	22,684.28
2010	76,975.36	61,384.69	24,875.04	19,900.03
2011	75,720.55	58,310.26	26,938.83	21,551.06
2012	71,334.48	54,268.71	26,184.4	20,947.52
2013	67,603.28	55,859.11	25,170.6	20,136.48
2014	70,797.99	57,853.91	23,674.85	18,939.88
2015	70,178.38	59,300.85	22,869.98	18,295.98
2016	70,155.58	61,509.79	22,490.55	17,992.44
2017	72,296.13	62,456.92	23,754	19,003.20
2018	73,605.84	62,198.53	22,208.84	17,767.07

*Source: EEA,[env_air_gge] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en Last update: 09-06-2020 * Estimate = 80% of Ammonia CO_2 DATA OUTPUT FILE: CO2_env_air_gge_TD.xls.*

Annex 14 Explanation of calculations

Cost of carbon reduction

The cost of the carbon reduction can be characterised as the cost per tonne of CO_2 reduced as a result of new investment in decarbonising technologies. The figures for different technologies are presented in Table 45. The efficiencies of carbon cost reduction are considered high if they are close to the lowest possible value for the selected technology. Efficiency in this instance does not refer to relative efficiency between different technologies.

Production cost increase

The production cost impact is calculated directly from estimates of production costs (including CAPEX) for new technologies compared to old technologies. This means new investment in breakeven technology would be feasible if the gain from reducing the output of CO_2 (and selling that) would just counterbalance the cost of the increased production cost per unit of output.

The figures for different technologies are presented in Table 45.

Subsequent adjustments to these variables

In addition, we may estimate the cost increase when products are tendered in an industry with market power. For this purpose, market power pricing is approximated by cartel average price increases from the EU study on cartels by Oxera and Komninos (2009)

Bidding on a single project basis like the funding gap approach may create monopoly pricing margins on top of x-inefficiency costs. Monopoly pricing is here approximated by cartel average price increases from the EU study on cartels by Oxera and Komninos (2009) In the second case, -x-inefficiency costs will be estimated from the economics literature on x-inefficiency. The monopoly margin would then be calculated on top of the x-inefficiency for the funding gap approach.

Competitive Effects

Competitive effects describe whether, for the given funding mechanism and industry, competitive market pressures will be strong to achieve a low cost, low price or efficient CO_2 reduction. The fixed intensity approach is considered to have no change on competitive effects, due to low overall predicted impact of the measure when instituted on its own. The CCfD multi-industry scheme has high competition, due to the multiple industry operators that may potentially be competing against each other in tenders. The CCfD single industry scheme is considered to have low competition, due to the generally concentrated nature of each industry on its own, apart from the cement industry, which may be considered moderately competitive compared to steel and fertilisers. The funding gap scheme is considered to have low competition due to the limited competitive pressure induced by administrative allocation of funding by individual project.

Table 48: Funding Approaches: Impacts by Industry and Technology

Funding	**Fixed aid intensity**				**CCfD multi-industry tender**				**CCfD industry by industry tender**				**Funding gap**			
Impacts	CO_2 reduction	Production cost impact	Cost of CO_2 reduction	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO2	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO2	Competitive effects	High CO_2 reduction	Production cost impact**	Cost of CO_2 reduction*	Low competition
							High cost efficiency of CO_2 reduction				Moderate cost efficiency of CO_2 reduction	Low competition		Production cost up for x inefficiency	Low cost efficiency of CO_2 reduction	Low competition
STEEL																
Hydrogen Direct Reduction (at 40 EUR/MWh cost of electricity to produce hydrogen)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	31	18	High competition	High CO_2 reduction	31	21	Low competition	High CO_2 reduction	37	25	Low competition
Smelting Reduction with CCS	Low	Low	Little or no additional CO_2 reduction beyond baseline	No change	CO_2 reduction dependent on bid value of CO_2 certificates	55	36	High competition	High CO_2 reduction	55	42	Low competition	High CO_2 reduction	65	44	Low competition

			learning effect													
Hydrogen Direct Reduction (at 60 EUR/MWh cost of electricity to produce hydrogen)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	98	57	High competition	High CO_2 reduction	98	66	Low competition	High CO_2 reduction	116	79	Low competition
Electric Arc Furnace (EAF) [current method]	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	11	6	High competition	High CO_2 reduction	11	7	Low competition	High CO_2 reduction	13	9	Low competition
CEMENT																
Oxyfuel	Low	Low	Little or no additional CO_2 reduction beyond	No change	High CO_2 reduction	37	60	High competition	High CO_2 reduction	37	65	Moderate competition	High CO_2 reduction	44	62	Low competition

			baseline learning effect													
Electrification with CCS (40 EUR/MWh) **	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	43	66	High competition	High CO_2 reduction	43	71	Moderate competition	High CO_2 reduction	51	72	Low competition
Electrification with CCS (60 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	58	89	High competition	High CO_2 reduction	58	96	Moderate competition	High CO_2 reduction	68	97	Low competition
AMMONIA																
Steam methane reforming + CCS	Low	Low	Little or no additional CO_2 reduction beyond baseline	No change	CO_2 reduction dependent on bid value of ETS	64	39	High competition	High CO_2 reduction	64	45	Low competition	High CO_2 reduction	76	49	Low competition

			learning effect		certificates											
Water Electrolysis (Hydrogen at 40 EUR/MWh Electricity)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	199	108	High competition	High CO_2 reduction	199	125	Low competition	High CO_2 reduction	235	151	Low competition
Water Electrolysis (Hydrogen at 60 EUR/MWh Electricity)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	394	215	High competition	High CO_2 reduction	394	249	Low competition	High CO_2 reduction	465	300	Low competition

*Source: UEA, Materials Economics. Notes: * including extra mark-up in the low competition situation of 16% or in the moderate competition situation of 8%. ** including extra cost from x inefficiency due to limited ability to understand costs at 18%.*

Table 49: Sensitivity of Funding Approaches Impacts by Industry and Technology: 25% Cost Decline

Funding	**Fixed aid intensity**				**CCfD multi-industry tender**				**CCfD industry by industry tender**				**Funding gap**			
Impacts	CO_2 reduction	Production cost impact	Cost of CO2 reduction	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO_2	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO_2	Competitive effects	High CO_2 reduction	Production cost impact**	Cost of CO_2 reduction*	Low competition
							High cost efficiency of CO_2 reduction				Moderate cost efficiency of CO_2 reduction	Low competition		Production cost up for x inefficiency	Low cost efficiency of CO_2 reduction	Low competition
STEEL																
Hydrogen Direct Reduction (at 40 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	23	14	High competition	High CO_2 reduction	23	16	Low competition	High CO_2 reduction	27	19	Low competition
Smelting Reduction with CCS	Low	Low	Little or no additional CO_2 re-	No change	CO_2 reduction dependent	41	27	High competition	High CO_2 reduction	41	31	Low competition	High CO_2 reduction	49	33	Low competition

			duction beyond baseline learning effect		on bid value of CO_2 certificates											
Hydrogen Direct Reduction (at 60 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	74	43	High competition	High CO_2 reduction	74	50	Low competition	High CO_2 reduction	87	59	Low competition
Electric Arc Furnace (EAF) [current method]	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	8	5	High competition	High CO_2 reduction	8	5	Low competition	High CO_2 reduction	10	7	Low competition
CEMENT						0	0									

Oxyfuel	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	28	45	High competition	High CO_2 reduction	28	49	Moderate competition	High CO_2 reduction	33	46	Low competition
Electrification with CCS (40 EUR/MWh) **	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	32	50	High competition	High CO_2 reduction	32	53	Moderate competition	High CO_2 reduction	38	54	Low competition
Electrification with CCS (60 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline	No change	High CO_2 reduction	44	67	High competition	High CO_2 reduction	44	72	Moderate competition	High CO_2 reduction	51	73	Low competition

			learning effect													
AMMONIA						0	0									
Steam methane reforming + CCS	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	48	29	High competition	High CO_2 reduction	48	34	Low competition	High CO_2 reduction	57	37	Low competition
Water Electrolysis (Hydrogen at 40 EUR/MWh Electricity)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	149	81	High competition	High CO_2 reduction	149	94	Low competition	High CO_2 reduction	176	113	Low competition
Water Electrolysis (Hydrogen at 60	Low	Low	Little or no additional CO_2	No change	CO_2 reduction	296	161	High competition	High CO_2 reduction	296	187	Low competition	High CO_2 reduction	349	225	Low competition

EUR/MWh Electricity)	re-duc-tion be-yond base-line learn-ing effect	de-pend-ent on bid value of ETS certif-icates

*Source: UEA, Materials Economics. Notes: * including extra mark-up from low competition at 16% or moderate competition at 8%. ** including extra cost from x inefficiency due to limited ability to understand costs at 18%.*

Table 50: Sensitivity of Funding Approaches Impacts by Industry and Technology: 25% Cost Increase

Funding	**Fixed aid intensity**				**CCfD multi-industry tender**				**CCfD industry by industry tender**				**Funding gap**			
Impacts	CO_2 reduction	Production cost impact	Cost of CO2 reduction	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO_2	Competitive effects	CO_2 reduction	Production cost impact	Cost of CO_2 reduction*/tonne CO_2	Competitive effects	High CO_2 reduction	Production cost impact**	Cost of CO_2 reduction*	Low competition
							High cost efficiency of CO_2 reduction				Moderate cost efficiency of CO_2 reduction	Low competition		Production cost up for x inefficiency	Low cost efficiency of CO_2 reduction	Low competition
STEEL																
Hydrogen Direct Reduction (at 40 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	39	23	High competition	High CO_2 reduction	39	26	Low competition	High CO_2 reduction	46	31	Low competition
Smelting Reduction with CCS	Low	Low	Little or no additional CO_2 re-	No change	CO_2 reduction dependent	69	45	High competition	High CO_2 reduction	69	52	Low competition	High CO_2 reduction	81	55	Low competition

			duction beyond baseline learning effect		on bid value of CO_2 certificates											
Hydrogen Direct Reduction (at 60 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	123	71	High competition	High CO_2 reduction	123	83	Low competition	High CO_2 reduction	145	99	Low competition
Electric Arc Furnace (EAF) [current method]	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of CO_2 certificates	14	8	High competition	High CO_2 reduction	14	9	Low competition	High CO_2 reduction	16	11	Low competition
CEMENT						0	0									

Oxyfuel	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	46	75	High competition	High CO_2 reduction	46	81	Moderate competition	High CO_2 reduction	55	77	Low competition
Electrification with CCS (40 EUR/MWh) **	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	High CO_2 reduction	54	83	High competition	High CO_2 reduction	54	89	Moderate competition	High CO_2 reduction	63	90	Low competition
Electrification with CCS (60 EUR/MWh)	Low	Low	Little or no additional CO_2 reduction beyond baseline	No change	High CO_2 reduction	73	111	High competition	High CO_2 reduction	73	120	Moderate competition	High CO_2 reduction	86	121	Low competition

			learning effect												
AMMONIA						0	0								
Steam methane reforming + CCS	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	80	49	High competition	High CO_2 reduction	80	57	Low competition	High CO_2 reduction	94	61	Low competition
Water Electrolysis (Hydrogen at 40 EUR/MWh Electricity)	Low	Low	Little or no additional CO_2 reduction beyond baseline learning effect	No change	CO_2 reduction dependent on bid value of ETS certificates	249	135	High competition	High CO_2 reduction	249	157	Low competition	High CO_2 reduction	294	189	Low competition
Water Electrolysis (Hydrogen at 60	Low	Low	Little or no additional CO_2	No change	CO_2 reduction	493	269	High competition	High CO_2 reduction	493	312	Low competition	High CO_2 reduction	581	375	Low competition

EUR/MWh Electricity)	reduction beyond baseline learning effect	dependent on bid value of ETS certificates

*Source: UEA, Materials Economics. Notes: * including extra mark-up from low competition at 16% or moderate competition at 8%. ** including extra cost from x inefficiency due to limited ability to understand costs at 18%.*

Study Item 3

Annex 15 List of references to economic parameters used for eligibility for exemptions for EIUs

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Annex 16 RES/CHP levies and eligibility for exemptions per country

In this annex, we provide an overview of the RES and CHP levy systems, their reforms, the theoretical minimum, and an overview of the levy levels for each country included in the support study. In addition, we provide a description of where the levy calculations were updated relative to the data for the Fitness check for Germany, France and Latvia.

1. **Austria:**
   - The Fitness Check collected RES levy data from 2012 to 2018.
   - Austria has a two-part levy system. First, Austria has a flat RES rate and then a general RES levy rate. The previous report calculated a total rate for RES charges. Levy rates in Austria are structured based on connected voltage levels, as well as demand and peak demand. To account for this, the Fitness Check made additional assumptions for each consumption band.[313] Austria introduced a reduction on RES levies for households. There were no exemptions for non-households.
   - To calculate the minimum effective levy, we took the lowest of levies calculated for each consumption band.
2. **Croatia:**
   - The Fitness Check collected RES levy data from 2014 to 2018.
   - Croatia has a flat rate levy. In addition, it charged different rates depending on certain criteria.[314] These criteria are roughly similar to EIU users eligible for exemptions in Annex 3 of the EEAG regulations. Therefore, it has been assumed that firms in sectors in Annex 3 of EEAG benefit from the exemptions.
   - The minimum effective levy was set to the reduced levy rate for each year.
3. **Denmark:**
   - The support study collected RES levy data from 2011 to 2018.
   - From 2011-2015, all firms (both Non-EIUs and EIUs) can receive an exemption if they produce their own power. In addition, reduced levy rates applied for firms with electricity consumption over 100Gwh per year. Both of these regulations were assumed to apply to firms in the largest consumption band, "IF".[315]
   - In September 2015, Denmark introduced a reform that set a reduction by a fixed subsidy rate, which cannot exceed 85% of the levy. Only firms in sectors listen in Annex 3 of EEAG were eligible.[316]
   - In 2016, Denmark extended the eligibility for the subsidy to firms in Annex 5, but only if these firms had an electro-intensity higher than 20%.[317] There was no electro-intensity requirement for Annex 3.
   - The minimum effective levy was set to the rate for firms above 100GWh from 2011 to 2015. For the time period from 2016 to 2018, the minimum was set to 85% of the levy.
4. **Estonia:**
   - The support study collected RES and CHP levy data from 2008-2018.

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[313] Support study, Annex 6.3, tab "Austria".
[314] Specifically, there is a different rate when the user is in the greenhouse gas allowances scheme, a scheme for firms with large carbon emissions. Examples of firms in this category are firms with a thermal output exceeding 20MW, Oil Refineries and Steel refineries. Thus, these criteria are roughly similar to EIU users eligible for exemptions in Annex 3 of the EEAG regulations. Therefore, it has been assumed that firms in sectors in Annex 3 benefit from these lower rates.
[315] Support study, Annex 6.3, tab "Denmark".
[316] Support study, Annex 6.2, cell G38. The discount only applies on the PSO charge above 20,000 Danish Krone.
[317] SA.44683. p. 2.

- Estonia did not introduce exemptions for EIUs during the 2008-2018 time period according to the Fitness check.
- The minimum levy was therefore set to the levy before reductions.

5. **France:**
   - The support study collected RES, CHP and other levy data from 2011-2015.
   - Throughout this period, France had a general levy ("CSPE") from which the RES and CHP subsidies were financed.[318] The share of this levy that was spent for RES and CHP support was estimated by France on an annual basis. We use these yearly estimates, rather than the average for 2003-2015 period as was done in the support study.[319] In this regime, France sets limits to the amount firms have to pay for levies.[320] First, the regulations set an absolute limit by site. This limit is then adjusted for inflation each year. Second, there is a limit of 0.5% of value added for firms who consume more than 7GWh of electricity.[321]
   - For these years, the minimum levy was set to zero as the levy rate per site would be lower the larger the electricity consumption of the site and would converge to zero in infinity.
   - In 2015 there was a change in the RES and CHP support mechanism when France switched to a system of electricity tax rates rather than levies.[322] Electro-intensive firms received a lower tax rate than other firms. RES and CHP were still subsidized, but the support now came from the general budget. In addition, the set of criteria for what constitutes an electro-intensive firm and accompanying reductions/lowered tax rates were calculated differently. Because of this switch in regime, we set the RES and CHP levies for France in the years 2016-2018 to zero.
   - For the simulation exercise in question 3.2.e, we were asked to consider scenarios both without France and with France, given the importance of France's turnover in the set of eleven countries for which we have consumption data. To do so, we construct a hypothetical levy for 2018 based on the electricity tax rate applicable in the sectors we study. In 2018, France had a general electricity tax rate of 2.25ct/kWh.[323] France grants exemptions and reductions to eligible industries. We calculated the hypothetical effective levies based on this tax rate and the corresponding exemptions or reductions[324] and used them in the simulations to investigate the impact of the different levy change scenarios on profitability.

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[318] In 2000, Law n°2000-108 sets out a framework to support renewable energies. This law was modified by Law n°2005-781 in 2005. The provisions of Law n°2000-108 were partially encoded into article L.121-7 of the "code de l'énergie". Decrees on 17 November 2008 and 23 December 2008 set the level of subsidies to support wind energy. See SA 36511, para. 6-7, 8,9, 13. This regulation incorporates RES and CHP levies into a general electricity levy rate, the CSPE. The percentages of importance of the RES and CHP levies in the CSPE rate vary by year. France itself estimated this breakdown by year. See SA.36511, para. 132.

[319] The percentages of importance of the RES and CHP levies in the CSPE rate vary by year. France itself estimated this breakdown by year. See SA.36511, para. 132.

[320] There is a general electricity levy rate, the CSPE. This levy rate was multiplied by 0.39 in the Fitness check to reflect that on average between 2003 and 2015 39% of the CSPE was used to finance RES. See Annex 6.3 of the Fitness Check.

[321] See SA.36511, para. 21.

[322] See SA.43468, para. 4: "Le taux de la TICFE a été porté à 22,5€/MWh à partir du 1er janvier 2016 afin d'intégrer la contribution au service public de l'électricité (CSPE) en vigueur jusqu'au 31 décembre 2015 dans la TICFE".

[323] See SA.43468, para. 4.

[324] France exempts sectors C20.11 and C20.13, see "Circulaire du 5 juillet 2019 Taxe Intérieure sur la Consommation Finale d'Électricité (TICFE), Section I.A, p. 27. Electro-intensive firms were eligible for several reductions. For this regulation, an electro-intensive firm was defined as a firm where the payable tax was more than 0.5% of its gross value added. First, the regulation provides reductions to sectors that are electro-intensive but not "at-risk" of relocation based on Annex II of the Communication 2012/C 158/04. For these sectors, firms

6. Germany

- The support study collected RES and CHP levy data from 2008-2018.
- The support study assumed that exemptions were introduced in 2012. However, there were additional national legislations outlining exemptions in 2004 and 2009.[325] We incorporated the exemptions of these legislations into the levy calculations. Furthermore, Germany introduced additional legislation in 2014 and 2017.
- From 2004 to 2012, a company was eligible for exemptions if it had electricity consumption above 10GWh and an electro intensity of at least 15%. In this case, it had to pay the full EEG-surcharge for 10% of its energy consumption and the reduced EEG-surcharge of 0.05 cents/kWh for the remaining 90%. However, if the firm had an energy consumption above 100GWh and an electro intensity of at least 20% the EEG-surcharge is reduced to 0.05 cents/kWh for its entire electricity consumption. The Fitness check calculated levies and subsidies for EIUs assuming an electro-intensity of 20%. Figure 56 shows the previous figure and the updated one. These results illustrate that EIUs already received subsidies before the 2012-2018 time period.
- In 2012, additional changes were made to the regulation, which went into effect in 2013.[326] In 2014, the regulations brought the definition of an EIU in line with the Guidelines by restricting eligibility to Annex 3 and 5, which went into effect in 2015. In addition, new electro-intensity requirements and mechanisms were introduced for firms in Annex 3 and 5.[327] In 2017, a new regulation was passed with further adjustments of the criteria, which came into effect in 2018. [328]
- Given that the exemptions for firms depend on the electricity consumption and the electro-intensity throughout 2011-2018, we have updated levy rates for each sector using the sector's respective average electricity consumption and the calculated electro-intensity.
- CHP levy regulation operated in addition to the RES levies. From 2011-2016, the CHP levy structure had two rates, one up to 1GWh and one for consumption

pay 0.2ct/kWh when their kWh/GVA is larger than 3, 0.5ct/kWh if their kWh/GVA is between 3 and 1.5 and 0.75ct/kWh otherwise. Sectors that are electro-intensive and "at-risk" based on Annex II (copper, basic iron, pulp) pay the following for the same set of ranges: 0.1ct/kWh, 0.25ct/kWh and 0.55ct/kWh otherwise. Sectors that are deemed "hyper-electro-intensive" are those that have a kWh/GVA above 6 and a trade intensity of >25%. These sectors pay 0.05ct/kWh. Only C24.42 and C20.11 are eligible for this exemption according to the data, but C20.11 is already exempt. SA.43468, para. 4, 11-14.

[325] In 2004, there was a modification of the EEG law which introduced a possibility of levy reductions for undertakings consuming more than 10GWh (100 GWh) per year and exceeding 15% (20%) electro-intensity and for trains (§16: Besondere Ausgleichsregelung). Undertakings need to apply for the exemption and obtain it for one year period starting on 1 January, administered by the Bundesamt für Wirtschaft und Ausfuhrkontrolle. The EEG law was further revised in 2009 (levy reductions for energy-intensive users discussed in §40-44).

[326] Firms now need at least a 14% electro-intensity in the previous financial year. For consumption up to 1 GWh, firms paid the full EEG-surcharge; for consumption between 1 GWh and 10 GWh, firms paid 10 % of the EEG-surcharge; for consumption between 10 GWh and 100 GWh, firms paid 1% of the EEG-surcharge; for consumption above 100 GWh, firms paid 0.05 cent/kWh; for consumption above 100 GWh and electro-intensity above 20%, RES levy will be limited to 0.05 cent/kWh for the EIU's entire electricity consumption. In addition, there were adjustment plans that cap RES levies additionally as of 2014 (details par 28-29 SA.33995).

[327] There was a required electro-intensity above 16% in 2015 and 17% as of 2016 for undertakings of Annex 3. There was a required electro-intensity above 20% for undertakings of Annex 5 for both these years. There were no exceptions on the 1 GWh. Eligible firms paid only 15% of the charge on their consumption above 1 GWh. In addition, there were caps of 0.5% of the GVA for undertakings who had at least 20% of electro-intensity and 4% of the GVA for undertakings who had an electro-intensity below 20%. In addition, the charge above 1 gigawatt-hour could not fall below the following value: (i) 0.05 cents per kilowatt-hour at consumption points at which the undertaking is allocated to a sector with the serial number 130, 131 or 132 pursuant to Annex 4, or (ii) 0.1 cents per kilowatt-hour at other consumption points.

[328] The required electro-intensity for a firm in Annex 3 was set to 14% and 20% for firms that are in a sector of Annex 5. Eligible firms pay the same charge on the first GWh, but then pay a reduced rate afterwards: They pay 15% of the full EEG surcharge if their electro-intensity is higher than 17%, and 20% if the electro-intensity is higher than 14% but below 17%. The limits on the minimum values remained the same, as did the maximum payments based on gross value added.

beyond 1GWH. However, firms that were eligible for reductions received reductions on the rate beyond 1GWh. [329] In 2017, the CHP levy system switched to one levy rate for all consumption. Reductions then applied similarly to the RES regulations.[330] However, there was a transition regime in place for 2017 and 2018 which we applied.[331]

- For the effective minimum levy, we took the theoretically possible minima for RES and CHP levies separately depending on the system and legal floors and then added these up.[332]

7. **Greece:**
   - The Fitness check collected RES and CHP levy data from 2011-2018.
   - Greece had a general levy rate to finance RES and CHP, which was introduced in 1999. The rate depends on the voltage. There is a maximum amount of 600.000 euros that firms have to pay, though this amount was not reached in the calculations for the support study.[333]
   - Greece did implement an additional exemption in January 2019 for EIUs, but this is outside the scope of our time period.
   - To calculate the minimum effective levy, we took the lowest of levies calculated for each consumption band.

8. **Italy:**
   - The Fitness check collected RES and CHP levy data from 2011-2018.
   - In 2008, Italy introduced its first regulations designed at reducing levy rates. This system was based on the size of electricity consumption and the type of voltage. Thus, firms with a consumption of more than 45GWh were eligible for reductions. The support study incorporated these reductions when calculating levy rates for firms, but did not classify them as exemptions. We adjusted this to differentiate between rates before and after exemptions. [334]
   - In July 2013, a new regulation was introduced to bring the criteria in line with the Guidelines.[335] While the support study assumed that the previous regime

[329] See https://www.netztransparenz.de/KWKG/KWKG-Umlagen-Uebersicht/KWKG-Aufschlaege-Vorjahre.
[330] See the KWKG 2017, para. 27, available at https://www.bmwi.de/Redaktion/DE/Downloads/Energie/kwkg.pdf?__blob=publicationFile&v=6.
[331] See the KWKG 2017, para. 36.
[332] For the CHP levies, we took the rate for consumption beyond 1GWh for EIUs from 2011 to 2018 as the lower bound. The one exception is 2012, where the rate below 1GWh was lower. For this year, we took an average of this baseline levy and the recuded levy over 1GWh paid for a firm that consumes 100GWh. For the RES levies, we took the lower bound of 0.05ct/kWh from 2011 to 2014. From 2015 to 2018, the minimum is determined by the legislation at 0.1ct/kWh, except for sectors C24.42, C24.43, and C24.44, where the minimum is set at 0.05ct/kWh.
[333] See support study, Annex 6.3, sheet "Greece".
[334] The reductions varied by connected voltage level and level of energy consumption. For example, there was no reduction for customers with low voltage, while there was a 100% reduction for medium voltage and consumption of more than 8 GWh/month. Furthermore, there was a 50% reduction for high voltage and consumption between 4-12 GWh/month, while there was a 100% reduction when electricity consumption exceeded 12 GWh/month. The support study assumed that users with a consumption larger than 70 GWh have a high voltage connection.
[335] See SA.38635. The eligibility requirements are (i) a yearly energy consumption above 2.4 GWh/year (ii) belong to the manufacturing sector according to the national ATECO (NACE) classification ("extractive" sectors from Annex 3 or 5 were not covered initially and added in 2015) (iii) electricity costs represent at least 2% of annual turnover and (iv) firms have to be connected at least in one point in medium, high or very high voltage. Eligible firms receive a 15% reduction when they have an electro-turnover between 2% and 6%, a 30% reduction when the electro- turnover is between 6% and 10%, a 45% reduction when the electro- turnover is between 10% and 15%, and a 45% reduction and a 60% reduction when the electro-turnover is above 15%.
[335] In 2018, the eligibility conditions covered undertakings in sectors in Annex 3 of the EEAG or Annex 5 of the EEAG, and who have an electro-intensity (calculated in accordance with Annex 4 of the EEAG, thus based on GVA) of not less than 20, or who are in the energy-intensive list for 2013-2014, and have an annual consumption above 1 GWh/year.

was in play until the end of 2013, we have adjusted the calculations based on the assumption that each regime was effective for half of the year.

- Eligibility criteria in 2013 were based on a measure of electricity costs relative to turnover. These criteria were adjusted in 2018 with new regulation which defined eligibility in terms of electro-intensity based on gross value added, rather than turnover, in line with the EEAG 2014 Guidelines. Figure 57 shows the changes in 2013 relative to the support study.
- Italy also had a certificate scheme until 2014, for which no exemptions were given. This scheme required undertakings to purchase a certain number of certificates based on their electricity consumption

9. Latvia:

- The support study collected RES levy data from 2012-2018.
- In July 2015, Latvia introduced a system of exemptions for EIUs based on Annex 3 and 5, in addition to a required electro-intensity of 20%[336] Latvia granted a reduction of 85% of the prior year's levies.[337] These subsidies apply for consumption from 0.5GWh onwards.
- The notification of this measure was suspended in 2016 at Latvia's request but then continued in 2017.[338] Given that payments were made in 2017, we keep the assumption of the support study that the exemptions started in the year 2016.[339]
- Latvia also had CHP levies throughout the period. No exemptions were available for CHP levies.[340]
- For Latvia, the minimum effective levy from 2016-2018 was set to sum of the CHP levy and the maximum reduced RES levy amount.[341]

10. Lithuania:

- The support study collected RES levy data from 2010-2018.
- Lithuania introduced exemptions in April 2019, i.e. outside the time period of this study.
- Given that no exemptions were present, the minimum effective levy is the levy before reductions.

11. Poland:

- The support study collected RES and CHP levy data from 2012-2018.
- From 1 October 2005 until 2016 Poland had a certificate of origin scheme that required electricity consumers to purchase certificates to fund the RES and CHP subsidies.[342] This scheme was open to new beneficiaries until July 2016, but will continue to provide existing beneficiaries with certificates until 2035.

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[336] SA.42854, para. 24.
[337] If the current year's levy decreased by more than 15%, the effective levy in a given year can be negative. These were capped at zero.
[338] SA.42854, para. 24.
[339] See https://webgate.ec.europa.eu/competition/transparency/public.
[340] See SA.43410, para. 4-6. For rates, see the rates from 2012-2014 at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwi60sK03eHuAhUSHHcKHV-uBhwQFjABegQIARAC&url=https%3A%2F%2Fwww.sprk.gov.lv%2Fevents%2Fobligata-iepirkuma-un-jaudas-komponensu-videja-vertiba-no-nakama-gada-saglabata-lidzsineja&usg=AOv-Vaw2Q7T03v-IIjN97XUAi9AXJ and for the later years until 2018 at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiqk4P73uHuAhW7AhAIHaJsBkgQFjACegQIARAC&url=https%3A%2F%2Fwww.sprk.gov.lv%2Fsites%2Fdefault%2Ffiles%2Feditor%2FOIK_2018.pdf&usg=AOvVaw1f-8v1uCKWNTN-IdsuofwF.
[341] The reductions of 85% were based on the RES levy the year before, which were subtracted from the RES levy in the current year.
[342] This was approved under case SA.37345.

- The system works with a quota level, which sets a number of certificates required as a percentage on the consumption level (13-17%). These certificates then have a price associated with them. However, certificates were not required for electricity generated for own use. For undertakings generating electricity for their own use, 66,25% of consumed electricity is purchased in the electricity market and the rest comes from self-generation.[343] As a result, we have adjusted the levy rates for non-households to account for the potential subsidy due to self-generation. Figure 59 illustrates the changes as now levies paid by non-EIUs and EIUs diverge from levies paid by households due to this effect.
- From 2014 onwards, new regulations that made exemptions depend on electro-intensity and vary between 25% and 85% percent.[344] To be eligible, firms needed to have an electro-intensity of at least 3%. In 2016, these exemptions were restricted to firms in sectors of Annex 3 of EEAG, though grandfathering did occur.[345][346]
- For the period from 2014 to 2018, the minimum effective levy was set at 15% of the levy, the maximum reduction possible. Before this period, the minimum levy was set at the amount that was calculated based on self-generation, which was eligible for a reduction.

12.Romania:

- The support study collected RES levy data from 2011-2018.
- In 2014, Romania created exemptions for firms in in sectors of Annex 3, whereby there is a required minimum of 5% electro-intensity. The subsidies are a percentage of the levy, and vary by electro-intensity.[347]

13.Slovakia:

- The support study collected RES levy data from 2011-2018.
- Slovakia had no exemptions. The support study collected data from 2011-2018.
- Given that there were no exemptions, the minimum levy was set to the levy before reductions.

14.Slovenia:

- The support study collected RES and CHP levy data from 2011-2018.
- Slovenia introduced exemptions in August 2015. Firms in sectors in Annex 3 and 5 are eligible, though there are different requirements and subsidies by Annex. Firms in sectors in Annex 3 must have an electro-intensity of at least 5%, while those in Annex 5 need at least 20%. Eligible firms in Annex 3 obtain a 70% reduction, whereas firms in Annex 5 have their contribution capped at 4% of gross value added.
- The minimum levy from 2015 to 2018 was set to the rate that included the largest possible reduction.

Table 51: RES and CHP legislations from 2012-2018

	Time Period	Eligibility	Exemptions
Austria	2012-2018	None	None

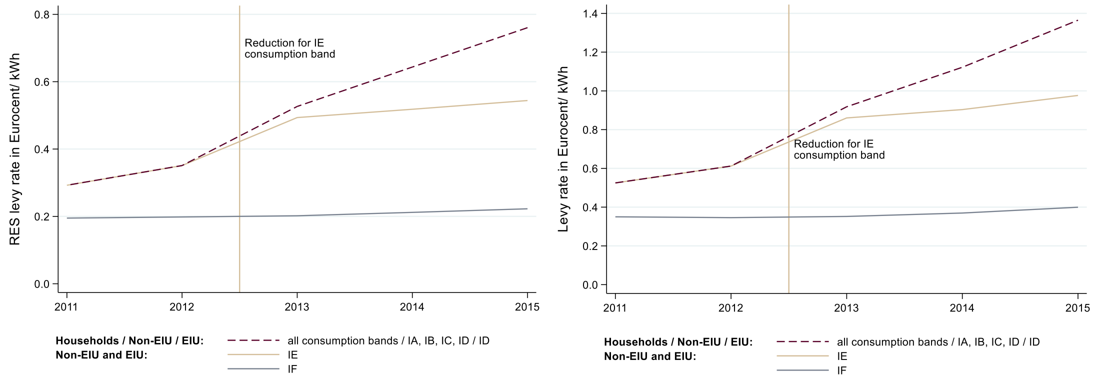
[343] Still, EIUs paid at least 15% of total cost of certificates and the other undertakings generating electricity for own consumption paid at least 20% of the total cost of certificates. This was considered compatible with the grandfathering rule (SA.37345, par 235).
[344] The national legal basis for exemptions is the Act of 26 July 2013 Amending the Energy Law and Certain Other Acts, and the RES Act of 20 February 2015. There is a 20% reduction for beneficiaries with an electro-intensity between 3% and 20%, a 40% reduction for beneficiaries with an electro-intensity between 20% and a 85% reduction for beneficiaries with an electro-intensity above 40%.
[345] See the support study, Section 6.2.
[346] See SA.37345.
[347] Firms have to pay 15% of the charge in the case of electro-intensities greater than 20%, 40% in the case of an electro-intensity between 10%-20%, and 60% in the case of an electro-intensity between 5%-10%.

Croatia	2014-2018	Similar conditions to Annex 3	Flat rate reduction
Denmark	2011-Sep 2015	Consumption > 100GWh	Reduced levy rate for consumption > 100GWh
	Sep 2015-2016	Annex 3	Fixed subsidy rate ≤ 85% of levy
	2016-2018	Annex 3; Annex 5, provided electro-intensity > 20%	Fixed subsidy rate ≤ 85% of levy
Estonia	2011-2018	None	None
France	2011-2015	Consumption size > 7GWh; total tax payment	Levy is capped. Absolute cap per site, and total tax ≤ 0.5% of added value if consumption > 7 GWh
Germany	2011-2013	Consumption > 10 GWh, provided electro-intensity > 15%	Reduced levy of 0.05 cents/kWh for 90% of consumption. Applies to full consumption if consumption > 100 GWh and electro-intensity > 20%
	2013-2015	Electro-intensity > 14%	Stepwise levy of 10% and 1% of full levy for consumption above 1GWH and 10GWh respectively. The levy for consumption above 100GWh was 0.05ct/kWh. For firms with electro-intensity >20% and >100GWh, rate is 0.05ct/kWh for entire consumption
	2015-2017	Annex 3 and annex 5, provided electro-intensity threshold is met (16% for Annex 3; 20% for Annex 5)	Levy reduced by 85% from 1 GWh onwards. A floor and a cap to the levy amount is stipulated based on gross value added ("GVA"): 0.5% of GVA for electro-intensity > 20% and 4% of GVA if electro-intensity <20%
	2018	Annex 3 and annex 5, provided electro-intensity threshold is met (14% for Annex 3; 20% for Annex 5)	Levy reduced by 85% from 1 GWh onwards if electro-intensity > 17%, and by 80% otherwise. The floor and cap of the levy continues to apply unchanged
Greece	2011-2018	Levy size threshold	Levy capped at €600.000 (never binding in data)
Italy	2011-Jul 2013	Consumption > 45 GWh	Reduction dependent on voltage and electricity consumption
	Jul 2013-2018	Threshold of electricity costs relative to turnover	Reduction dependent on electro-turnover
	2018	Annex 3 and annex 5, provided threshold met of electricity costs relative to gross value added	Reduction dependent on electro-turnover
Latvia	2012-2015	None	None
	2015-2018	Annex 3 and annex 5, provided electro-intensity > 20%	From consumption of 0.5 GWh onwards, reduction of 85% of prior year's levies
Lithuania	2011-2018	None	None
Poland	2012-2014	Self-generation	Exemption from tax
	2014-2018	Annex 3, provided electro-intensity > 3%	Exemptions depend on electro-intensity and vary between 25% and 85% percent
Romania	2011-2014	None	None
	2014-2018	Annex 3 provided electro-intensity > 5%	Percentage reduction of levy dependent on electro-intensity
Slovakia	2011-2018	None	None
Slovenia	2011-Aug 2015	None	None
	Aug 2015-2018	Annex 3 provided electro-intensity > 5%; annex 5 provided electro-intensity > 20%	Levy reduced by 70% for Annex 3; Levy capped at 4% of gross value added for Annex 5

Source: Support study and research by the authors.

The following figures present levy development for a firm with 20% electro-intensity in each consumption band for each country where we adjusted levy data from the Fitness Check support study.

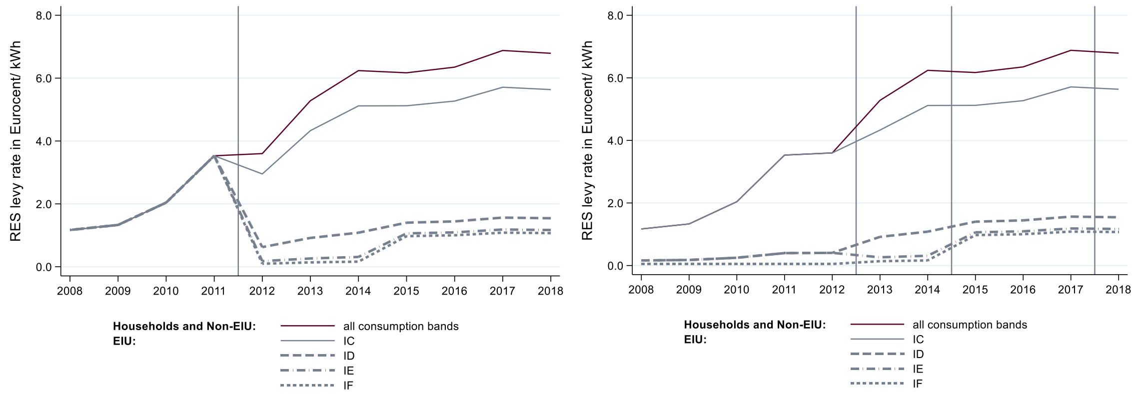
Figure 55: RES and CHP levies in France in the support study (left) and after adjustments (right)



levy for each of these categories were adjusted for each year based on France's calculations, rather than the average for the 2003-2015 time period.

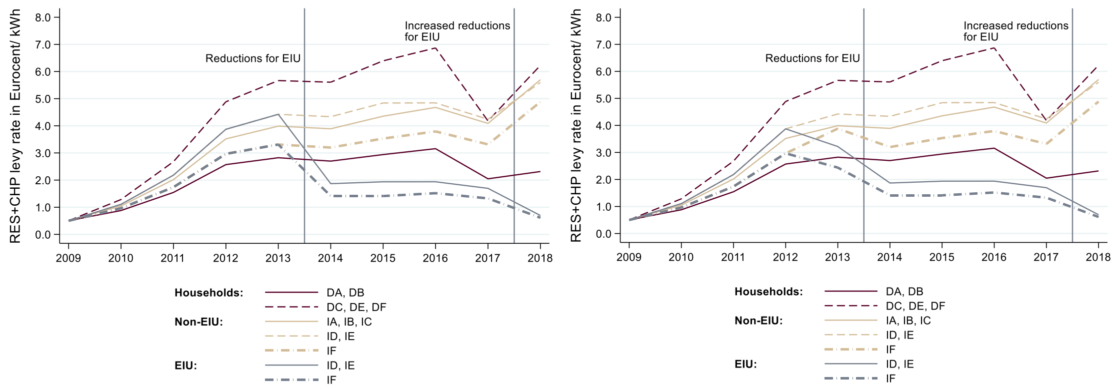
Source: Support study and research by the Authors. The left graph only denotes the RES levies in France, whereas the right graph depicts both RES and CHP levies. The share of RES and CHP levy in the general CSPE

Figure 56: RES levies in Germany in the support study (left) and after adjustments (right)



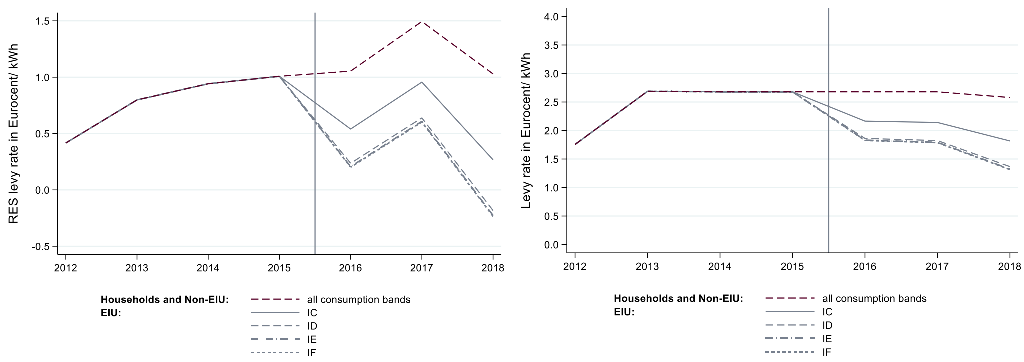
Source: Support study and research by the Authors.

Figure 57: RES levies in Italy in the support study (left) and after adjustments (right)



Source: Support study and research by the Authors.

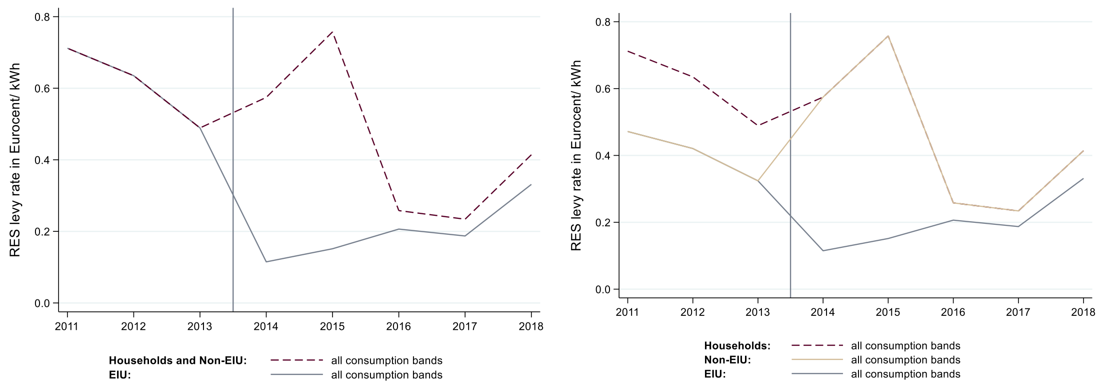
Figure 58: RES and CHP levies in Latvia in the support study (left) and after adjustments (right)



Note: CHP levies are included as the adjustment.

Source: Support study and research by the Authors.

Figure 59: RES levies in Poland in the support study (left) and after adjustments (right)



Source: Support study and research by the Authors.

Annex 17 Description of the data sources and the construction of variables for the econometric analysis

This Annex describes the steps that were taken to construct sectoral economic activity and the measures of electricity consumption, electricity price and electro-intensity.

Annex 17.1 Sectoral economic activity data

Sectoral economic activity data from Eurostat. Sectoral level data on economic activity is available in Eurostat's Structural Business Statistics database. For the years 2011-2018, per sector, country and year, we used the following variables:

- Turnover (in million euro),
- Gross operating surplus (in million euro),
- Value added at factor cost (in million euro),
- Purchases of energy products (in million euro),
- Total number of firms,
- Number of firms with more than 20 employees.

Data at several aggregation levels were used throughout the Study: 3-digit and 4-digit level from the at NACE Rev. 2 sector classification.

The relevant summary statistics are provided in Table 52 for the sample of 10 sectors used in the descriptive analysis presented in section 3.4. These statistics suggest that there exists substantial heterogeneity in economic activity across sectors, both when considering 3-digit and 4-digit NACE Rev. 2 sectors.

Table 52: Summary statistics of economic activity data provided from Eurostat for the years 2011-2018 for the sample of 10 sectors

	Observations	Completeness	Mean	Std. Dev	p5%	p95%
4-digit level						
Total number of firms	552	96%	375.7	1,015.0	5.0	3,325.0
Turnover (in million euro)	552	88%	2,670.7	5,696.0	47.7	13,303.6
Value added at factor cost (in million euro)	552	90%	566.8	1,076.9	6.5	2,568.0
Gross operating surplus (in million euro)	552	88%	187.8	319.0	2.0	709.1
Purchases of energy products (in million euro)	552	65%	206.2	478.5	0.4	838.0
3-digit level[1]						
Number of firms	704	98%	1581.9	2739.4	6.0	9106.0
Number of firms with more than 20 employees	704	92%	92.7	156.4	2.0	371.0

Source: Eurostat. Notes: [1] The 3-digit level statistics were calculated at the level above each respective sector. Given that there are two overlaps of 4-digit sectors, this leads to eight 3-digit sectors. [2] The unit of observation is a country-sector-year [3] A country-sector is included if it has at least one positive observation in the 2011-2018 time period. If there were no observations for the sector in a country in any year, the sector-country is not included in the dataset. As a result, the 3-digit level has more observations than the 4-digit level as the 3-digit level has at least one observation for each country across the time period.

Firm- and sectoral-level data from Amadeus. The Study exploits firm-level data on profitability from the Bureau van Dijk's (2010) Amadeus database for the years 2011-

2018. We use the unconsolidated version of the Amadeus database.[348] This database contains the name of all subsidiaries of a firm, the country code, the NACE identifier as well as measures of firms' performance and activity. Descriptive statistics for the data from Amadeus are included in Annex 18.

This database allows us to look at individual firms' outcomes and in particular profitability EBIT: Earnings Before Interest and Taxes. This is a great advantage of the Amadeus database with respect to alternative data sources since it is not easy to find good quality and complete financial data at the firm level. The data also provides information on firm size, allowing a distinction between average firm outcomes of the different size classes: small, medium and large enterprises.[349]

Annex 17.2 Electricity Consumption

First, we combine data on electricity consumption reported by Member States to DG COMP and DG CLIMA to obtain estimates for a sector-country-year where available. The DG CLIMA data goes from 2013-2016, while the DG COMP data goes from 2016-2019. When both data sources have data in 2016 for a sector-country, we use the data from DG COMP.

Furthermore, we use electricity consumption volume but not electricity purchases. We therefore only use observations of electricity consumption volume for Germany from DG Comp (but not the electricity purchases from DG CLIMA) and for Latvia from DG CLIMA (but the electricity purchases from DG COMP).

The data is further restricted to full information coverage or a single country. Thus, we exclude the combined countries "Austria Denmark Sweden". In addition, single observations provided "voluntarily by individual companies or business associations" are dropped from the CLIMA data as is information on "BE (flanders)".

Among Member States which were included in the support study, Italy, Romania, and Estonia did not provide data on the 4-digit NACE Rev.2 level. As a result, because of the missing electricity consumption volume, we cannot calculate levy exemptions for an estimated average firm. This is especially relevant for Italy and Romania, where the amount of exemptions depends on the electro-intensity.[350] In addition, the electricity price depends on the estimated size of a firm. We therefore leave these member states out of our calculations for the descriptive statistics and simulation. We do bring these countries in for the regression analysis as we can attribute consumption volumes to each band.

Second, we calculate the average electricity consumption volume per firm in a sector-country using electricity consumption and the number of non-small firms from Eurostat.

We calculate the average electricity consumption volume for a firm by dividing its sector electricity consumption volume by the number of firms with more than 20 employees. This measure was used in a study published by the European Commission (Trinomics et al., October 2020). The advantage of this approach is that very small firms do not obtain a disproportionate weight in the average. It allows to mitigate the likely bias due to the large

[348] These include information retrieved from unconsolidated financial statements as well as unconsolidated data provided in consolidated financial statements.

[349] We use the definition of firm size provided by Bureau van Dijk. Companies in Amadeus are considered to be very large when they match at least one of the following conditions: Operating Revenue >= EUR 100 million Total assets >= 200 million EUR (260 million USD), Employees >= 1,000. Companies with ratios Operating Revenue per Employee or Total Assets per Employee below EUR 100 (USD 130) are excluded from this category. Companies for which Operating Revenue, Total Assets and Employees are unknown but have a level of capital over EUR 5 million (USD 6.5 million) are also included in the category. Companies on Amadeus are considered to be large when they match at least one of the following conditions: Operating Revenue >= EUR 10 million (USD 13 million), Total assets >= EUR 20 million (USD 26 million), Employees >= 150; Not Very Large. Companies with ratios Operating Revenue per Employee or Total Assets per Employee below EUR 100 (USD 130) are excluded from this category. Companies for which Operating Revenue, Total Assets and Employees are unknown but have a level of Capital comprised between 500 thousand EUR (650 thousand USD) and EUR 5 million (USD 6.5 million) are also included in the category. Companies are considered to be small if they are not included in any other category.

[350] Italy had eligibility conditions from 2013-2018 based on electricity costs relative to turnover.

number of very small firms consuming little electricity, as would be expected in the manufacturing sector.

To calculate the number of firms with more than 20 employees in a 4-digit sector-country-year, we take several steps. We calculate the share of firms with more than 20 employees in the total number of firms in the relevant 3-digit NACE sector. It is only at this aggregation level that data is available in Eurostat for both the total number of firms and the number of firms with more than 20 employees. This share of firms with more than 20 employees is then multiplied by the total number of firms in the 4-digit sector to come up with the number of 20+ firms.

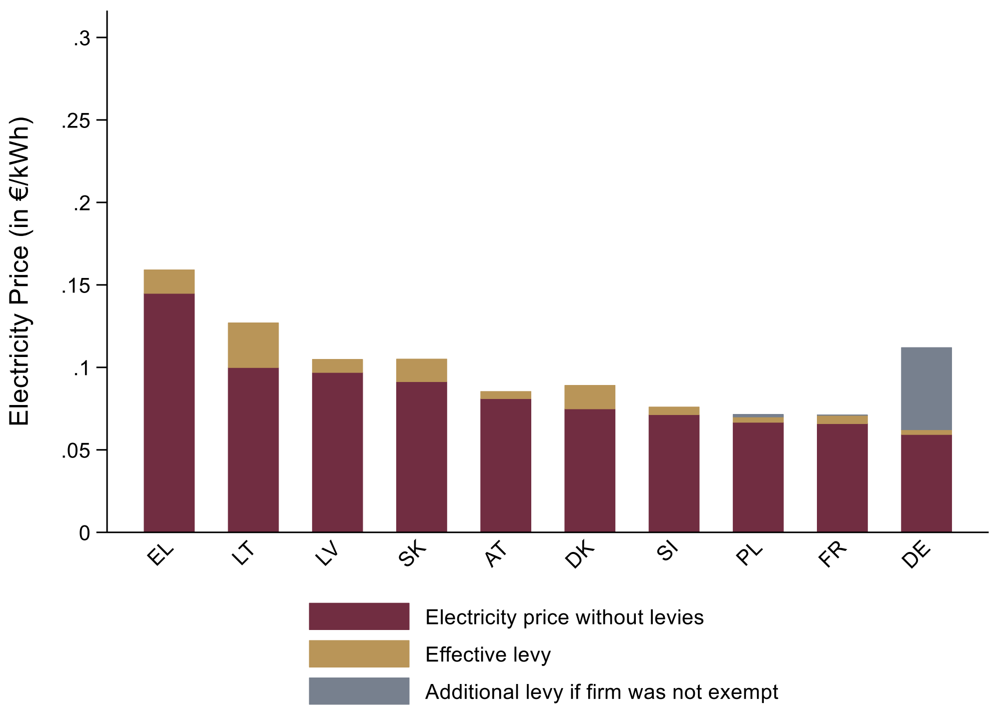
We finally sum up electricity consumption volume for a country and sector across all years for which the data is available and divide this sum by the total number of non-small firms in the country and sector. The result is the electricity consumption volume for a firm, averaged over time, for each country and sector.

Annex 17.3 Electricity Prices

We use industrial electricity prices provided by Eurostat at the country and year level by electricity consumption band for the period 2011-2018. We use electricity prices without recoverable taxes from Eurostat, which we adjust based on whether sectors were eligible for exemptions.

Eurostat's electricity prices are not sector-specific and cover the entire economy. Thus, it is likely that the vast majority of the firms reporting their electricity price to Eurostat are Non-EIUs and we expect these reported prices to include the full levy without reductions. To translate the electricity prices at country-level to sector-level prices, we use the information on the levy rates. For each sector, we calculate "effective electricity prices". We do so by subtracting any applicable subsidies for RES and CHP levies for eligible firms from the electricity price. If a firm is not eligible for any reductions, it pays the full electricity price. See Figure 60 as an example

Figure 60: Electricity price and RES and CHP levies in data processing, hosting and related activities in 2013



Source: Support study. European Commission, Eurostat, and own calculations.

To test the assumption that electricity prices include the full levy, we compared the "renewable taxes" provided by Eurostat in 2018 for each country (the exception was Germany with renewable taxed available only for 2019) and consumption band. If levies are comparable across consumption bands, electricity prices will also account for the full amount. If they do not, then the average electricity price might not include the full levy. We found that this assumption held for most countries. Lithuania, Slovakia, and Poland provided near identical rates across consumption bands. France did not have levies in 2018. Denmark and Latvia do not provide subsidies for an initial range of consumption, making the comparison difficult as the effective levy varies by consumption band. Slovenia, Austria and Greece base their levies on voltage levels and peak demand, such that levies actually vary by consumption band. This variation within levy levels thus makes a comparison hard to undertake.

For Germany, we found that the consumption band IF had an average levy of 3.8ct/kWh relative to the levy of 6.7ct/kWh for consumption band IA, which reflects the levy before reductions. A similar difference in levy also existed for other consumption bands. This result indicates that firms eligible for exemptions likely played a large role in reporting electricity prices for high consumption bands in Germany. We therefore adjusted the electricity prices in each consumption band upwards by the amount of the levy that was missing in this band relative to the full levy based on the percentage that was missing. We calculated this ratio based on the 2019 levies but apply it to the levies in Germany for each year. For example, for consumption band IF, we added 43% of the levy to the electricity price for each year. The adjustments for each consumption band are shown in Table 53. To evaluate the reasonableness of this adjustment, we compared these adjusted electricity prices, including exemptions, to several industry reports.

Table 53: Comparison of reported levy rates in Eurostat for Germany in 2019

Consumptionband	Levy IA (ct/kWh)	Levy (ct/kWh)	Difference (ct/kWh)	Difference (%)
IA	6.69	6.69	0.00	0%
IB	6.69	6.69	0.00	0%
IC	6.69	6.66	0.03	0%
ID	6.69	6.03	0.66	10%
IE	6.69	4.75	1.94	29%
IF	6.69	3.8	2.89	43%

Source: Eurostat and own calculations.

First, we compared the unadjusted and adjusted prices to the electricity prices calculated in "Electricity Costs of Energy Intensive Industries", a joint report of Ecofys, Fraunhofer-ISI, and GWS, which was published in 2015. The study combines publicly available data with information obtained from interviews with industry representatives to calculate the price components of electricity for different types of non-household users in Germany and other countries for the year 2013. This study focused on firms with a very high consumption level, which were often in consumption band "IG", for which Eurostat does not provide prices due to confidentiality reasons. The study shows that these firms pay dramatically less in taxes and levies than other firms. Furthermore, their electricity costs are often nearly entirely made up of the procurement costs of electricity, which are not firm-specific. Therefore, it seems reasonable to interpret the values calculated in this study as a lower bound for average electricity prices in the "IF" band for firms in the same sector. Comparing our unadjusted and the adjusted data, we see that electricity prices in our unadjusted data are often below theses lower bound, while the adjusted data exceed them. Thus, the adjusted electricity prices seem more reasonable.

Table 54: Electricity Price Comparison in 2013

Sector	Unadjusted elec. price (Euro/kWh)	Adjusted elec. price (Euro/kWh)	Elec. price from study (Euro/kWh)
Manufacture of pulp	0.050	0.073	0.066
Manufacture of basic iron, steel, and of ferro-alloys	0.049	0.072	0.065
Aluminium production	0.049	0.072	0.050
Copper production	0.050*	0.073	0.050

*Source: Own calculations for unadjusted and adjusted electricity prices 'Electricity Costs for Energy Intensive Industries', July 2015, Ecofys, Fraunhofer-ISI, and GWS. Data is always for 2013. Notes: The comparison *: In our unadjusted data, the electro-intensity for copper is too low for the sector to be eligible for the (nearly complete) exemption from the EEG surcharge. For this observation, we subtract the amount of this exemption from our data to compare it with the exempted firm from the example in the paper.*

Our second comparison is based on a breakdown of electricity prices from Eurostat, which includes a category called "energy and supply". Although this category can include additional components, we find that its values for 2013 are nearly identical to the procurement costs identified across several consumption bands in table 1 of the Ecofys, Fraunhofer-ISI, and GWS report. We therefore consider this another plausible lower bound for electricity costs. Table 38 provides an overview of these costs relative to electricity prices, both unadjusted and adjusted, from 2015 to 2016 for aluminium production. The unadjusted electricity prices are sometimes lower than the procurement costs, while the adjusted prices are above it, indicating that the adjustment again seems reasonable.

Table 55: Comparison of Prices and Procurement Costs

Year	Sector	Unadjusted price (Euro /kWh)	Adjusted price (Euro /kWh)	Procurement costs (Euro /kWh)
2016	Aluminium production	0.021	0.049	0.020
2017	Aluminium production	0.032	0.062	0.022
2018	Aluminium production	0.023	0.053	0.031

Source: Support study. European Commission, Eurostat, and own calculations. Procurement costs are the "energy and supply" variable from Eurostat.

Annex 17.4 Electro-intensity

Electro-intensity is an important variable in many Member States to calculate eligibility for exemptions. Electro-intensity is defined as the amount paid for electricity consumption, the electricity price times the volume, divided by the gross value added for a firm.

Based on provided electricity consumption data, we observed that variation of electro-intensity within a sector-country is limited variation across years. For example, 50% of the observations are within a 10% range of the mean for a given country-sector. Furthermore, the interquartile range for the absolute differences for electro-intensity around its median is 0.6%, while it is a 2.2% range between the 10th and 90th percentile. We therefore assume that electro-intensity is constant across years. This assumption also is in line with some countries that take averages of the several past years to determine eligibility.

However, it is important to note that electro-intensity can vary within a sector, for example, due to the technology that is used. We are not able to capture this by solely using the industry volume. To account for heterogeneity of electro-intensity within the industry, we therefore multiply the volume of an average firm in a consumption band times the price, and divide it by the average gross value added per firm. The average gross value added per firm is calculated as the industry gross value added, divided by the number of firms with more than 20 employees. Firms in different consumption band will thus have different electricity prices and volume, but similar gross value added. Because electricity volumes increase by consumption band, the electro-intensity will be higher for the consumption bands with higher volume.

However, we adjust the estimated levies and electricity prices when we have more precise information about the electricity consumption volume within a band. This happens for the estimated consumption band, based on actual industry volume information and the number of large firms. For this estimated consumption band, we use the calculated levies and prices using the actual average volume information reported by Member States to the Commission rather than the average volume within a consumption band indicated by Eurostat.

While the descriptive statistics use the estimated consumption band, the regression model takes a more nuanced approach by utilizing information on firm size in the Amadeus data. The Amadeus data has information on the size of the firm, which can be small, medium, "large and very large".[351] We match this information on firm size with consumption bands in the following way. First, attribute the estimated consumption band, based on the actual average volume for a firm, to the "large and very large" firms. Second, "medium firms" are attributed to one consumption band lower. For sectors in countries that did not have volume data, and thus no estimated consumption band, we take the mode of the consumption band of countries for which we do have estimates.

Annex 18 Detailed results from regression analysis and simulation

Table 56: Estimation results for `Manufacturing' – EBIT (in log) to industry-averaged and consumption band specific electricity prices (in log)

	(1) (AVE)	(2) (IA)	(3) (IB)	(4) (IC)	(5) (ID)	(6) (IE)	(7) (IF)
ln(Electricity price)	-0.43	-0.37	-0.59	-0.29	-0.095	0.032	0.024
	(0.015)***	(0.017)***	(0.020)***	(0.015)***	(0.012)***	(0.0071)***	(0.0057)***
ln(VA at NACE 2-dig.)	0.24	0.23	0.22	0.24	0.25	0.23	0.22
	(0.014)***	(0.014)***	(0.014)***	(0.014)***	(0.014)***	(0.014)***	(0.014)***
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nace 2dig. trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nace 2dig. trend-sq	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,619,333	1,620,199	1,620,199	1,619,465	1,618,121	1,617,844	1,607,451
R2 – adjusted	0.83	0.83	0.83	0.83	0.83	0.83	0.83

Notes: *(AVE)* refers to industry average. *(IA)/(IB)/(IC)/(ID)/(IE)/(IF)* refer to respective electricity consumption bands. Standard errors clustered at firm level in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on data from Amadeus, the Support study, Eurostat and the European Commission.

[351] We use the definition of firm size provided by Bureau van Dijk. Companies on Amadeus are considered to be very large when they match at least one of the following conditions: Operating Revenue >= EUR 100 million (USD 130 million), Total assets >= 200 million EUR (260 million USD), Employees >= 1,000. Companies with ratios Operating Revenue per Employee or Total Assets per Employee below EUR 100 (USD 130) are excluded from this category. Companies for which Operating Revenue, Total Assets and Employees are unknown but have a level of capital over EUR 5 million (USD 6.5 million) are also included in the category. Companies on Amadeus are considered to be large when they match at least one of the following conditions: Operating Revenue >= EUR 10 million (USD 13 million), Total assets >= EUR 20 million (USD 26 million), Employees >= 150; Not Very Large. Companies with ratios Operating Revenue per Employee or Total Assets per Employee below EUR 100 (USD 130) are excluded from this category. Companies for which Operating Revenue, Total Assets and Employees are unknown but have a level of Capital comprised between 500 thousand EUR (650 thousand USD) and EUR 5 million (USD 6.5 million) are also included in the category. Companies on Amadeus are considered to be medium sized when they match at least one of the following conditions: Operating Revenue >= EUR 1 million (USD 1.3 million), Total assets >= EUR 2 million (USD 2.6 million), Employees >= 15, Not Very Large or Large. Companies with ratios Operating Revenue per Employee or Total Assets per Employee below EUR 100 (USD 130) are excluded from this category. Companies for which Operating Revenue, Total Assets and Employees are unknown but have a level of Capital comprised between EUR 50 thousand (USD 65 thousand) and EUR 500 thousand (USD 650 thousand) are also included in the category. In Amadeus, companies are considered to be small if they are not included in any other category.

Table 57: Summary statistics of variables used in the econometric study

Variable	Firm size category	Mean	SD	P5	P95
EBIT (in K EUR)	All firms	643.7	12,363.1	1.0	1,811.1
	Large firms	4,164.7	34,201.7	90.3	12,622.7
	Medium firms	235.2	458.0	8.2	876.0
	Small firms	31.2	104.0	0.4	114.6
Electricity price (ct/kWh)	All firms	15.8	5.7	8.3	26.7
	Large firms	11.8	3.8	7.0	18.0
	Medium firms	15.7	5.3	8.6	26.7
	Small firms	16.9	5.9	9.6	26.9
Value added at factor cost (M EUR)	All firms	11,074.4	13,225.1	170.3	32,979.0
	Large firms	15,502.2	17,898.7	419.2	46,202.6
	Medium firms	12,911.7	13,749.2	273.9	34,154.5
	Small firms	8,412.8	10,469.4	127.8	30,241.0

Source: Own calculations based on data from Amadeus, the Support study, Eurostat and the European Commission.

Table 58: Estimation results for `Manufacturing', by consumption band – EBIT (in log) to electricity prices (in log)

	(1) (AVE)	(2) (IA)	(3) (IB)	(4) (IC)	(5) (ID)	(6) (IE)	(7) (IF)
Large firms							
ln(Electricity price)	-0.54	-0.50	-0.99	-0.67	-0.53	-0.12	-0.15
	(0.032)***	(0.038)***	(0.044)***	(0.033)***	(0.027)***	(0.017)***	(0.013)***
ln(VA at NACE 2-dig.)	0.14	0.091	0.072	0.13	0.15	0.14	0.14
	(0.032)***	(0.031)***	(0.031)**	(0.032)***	(0.032)***	(0.032)***	(0.033)***
Observations	208,916	209,442	209,442	209,229	208,862	208,773	206,783
R2 – adjusted	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Medium firms							
ln(Electricity price)	-0.44	-0.39	-0.73	-0.42	-0.23	-0.030	-0.034
	(0.023)***	(0.025)***	(0.030)***	(0.023)***	(0.018)***	(0.011)***	(0.0085)***
ln(VA at NACE 2-dig.)	0.17	0.16	0.14	0.18	0.19	0.18	0.16
	(0.022)***	(0.022)***	(0.021)***	(0.022)***	(0.022)***	(0.022)***	(0.023)***
Observations	628,813	629,128	629,128	628,951	628,514	628,406	621,968
R2 – adjusted	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Small firms							
ln(Electricity price)	-0.29	-0.30	-0.39	0.00040	0.19	0.18	0.16
	(0.028)***	(0.029)***	(0.033)***	(0.027)	(0.020)***	(0.012)***	(0.0093)***
ln(VA at NACE 2-dig.)	0.36	0.36	0.35	0.36	0.34	0.32	0.31
	(0.022)***	(0.022)***	(0.022)***	(0.022)***	(0.022)***	(0.022)***	(0.022)***
Observations	781,604	781,629	781,629	781,285	780,745	780,665	778,700
R2 – adjusted	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nace 2dig. trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nace 2dig. trend-sq	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: *(AVE)* refers to industry average. *(IA)/(IB)/(IC)/(ID)/(IE)/(IF)* refer to respective electricity consumption bands. Standard errors clustered at firm level in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on data from Amadeus, the Support study, Eurostat and the European Commission.

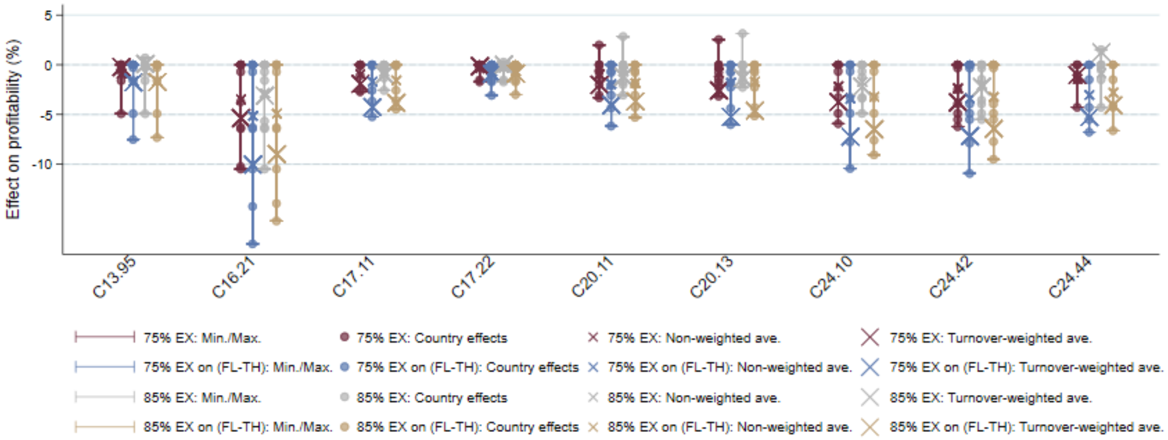
Table 59: Estimation results for `Manufacturing' – EBIT (in absolute in log) to industry-averaged electricity prices (in log) – different firm size classes – negative EBIT

	(1) (All)	(2) (Large)	(3) (Medium)	(4) (Small)
ln(Electricity price)	0.051	0.36	0.36	0.018
	(0.044)	(0.14)***	(0.095)***	(0.054)
ln(VA at NACE 2-dig.)	0.025	-0.0080	0.35	0.015
	(0.030)	(0.12)	(0.064)***	(0.034)
Year FE	Yes	Yes	Yes	Yes
Nace 2dig. trend	Yes	Yes	Yes	Yes
Nace 2dig. trend-sq	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	575,963	38,055	123,268	414,640
R2 – adjusted	0.73	0.62	0.57	0.60

Notes: Standard errors clustered at firm level in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

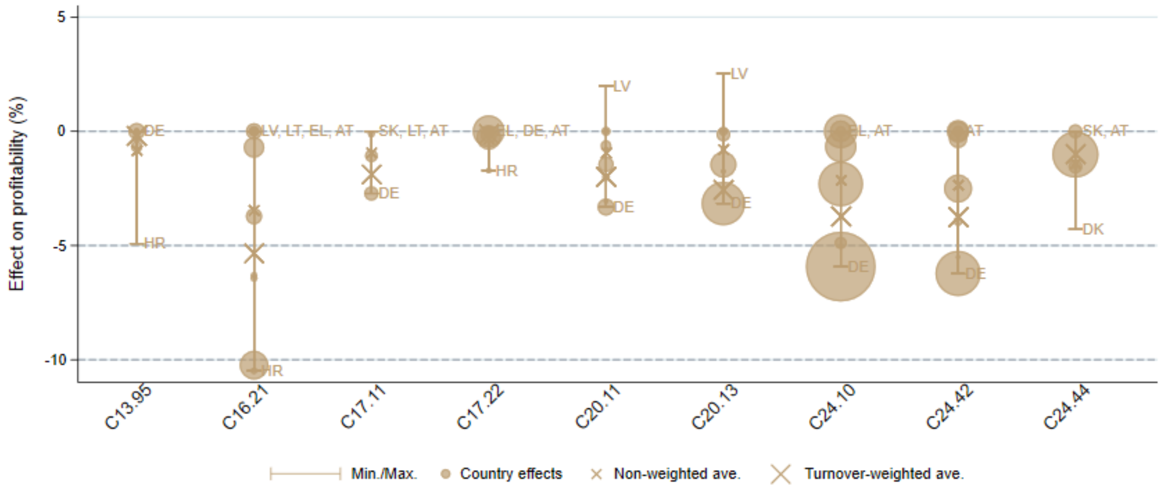
Source: Own calculations based on data from Amadeus, the Support study, Eurostat and the European Commission.

Figure 61: Simulation results (% effect on profitability) across sectors for exemptions conditional on the unexempted levy exceeding 2 ct/kWh and eligibility to exemptions in the status quo



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline. The exemptions are conditional on the unexempted levy exceeding 2 ct/kWh and the eligibility for exemptions in the respective country in the status quo. If unexempted levies were below the threshold, effective levies were set to the unexempted levy. If unexempted levies were above the threshold, exemptions were only applied if the sector already received exemptions in the status quo. Exemptions are calculated based on the unexempted levy or the difference between the unexempted levy and the threshold ("FL-TH").

Figure 62: Simulation results (% effect on profitability) across sectors for exemptions conditional on the unexempted levy exceeding 2 ct/kWh and eligibility to exemptions in the status quo with 75% exemption on the full levy



Source: European Commission, Amadeus and own calculations. All levy changes are calculated using the status quo effective levies as the baseline. The exemptions are conditional on the unexempted levy exceeding 2 ct/kWh and the eligibility for exemptions in the respective country in the status quo. If unexempted levies were below the threshold, effective levies were set to the unexempted levy. If unexempted levies were above the threshold, exemptions were only applied if the sector already received exemptions in the status quo. Exemptions are calculated based on the unexempted levy.

Table 60: Assessment of scenarios for country-sectors ("C/S") in the nine sectors and EU-11

Scenario	Maximising budget for RES and CHP support	Minimising distortion of competition within the EU	Minimising risk of relocation outside the EU
Harmonisation of effective levies to the highest unexempted levy level	Positive impact	Positive impact	High negative impact in 49 C/S, moderate negative impact in 28 C/S and limited negative impact in 2 C/S, no impact in 2 C/S.
No exemptions	Positive impact	Unclear	High negative impact in 8C/S, moderate negative impact in 9 C/S and limited negative impact in 30 C/S, no impact in 34 C/S.
-50%/-20%/-10% effective levy decrease	Negative impact	Positive impact	High positive impact for 2 C/S, moderate positive impact for 2 C/S. Limited positive impact for the remaining C/S.
+10%/+20 effective levy increase	Positive impact	Limited negative impact	Limited negative impact for all C/S
+50% effective levy increase	Positive impact	Negative impact	Limited negative impact for 77 C/S, moderate impact for 2 C/S
+100% effective levy increase	Positive impact	Negative impact	Limited negative impact in the majority of C/S, moderate negative impact in 6 C/S, and high negative impact in 2 C/S
+0.5 ct/kWh effective levy increase	Positive impact	Limited positive impact	Limited negative impact for the 79 of C/S. Moderate impact for 2 C/S
+1.0 ct/kWh effective levy increase	Positive impact	Limited positive impact	Limited negative impact for the majority of C/S. Moderate impact for 11 C/S

+1.5 ct/kWh levy increase	Positive impact	Limited positive impact	Limited negative impact for the majority of C/S, moderate negative impact in 25 C/S, high negative impact in 7 C/S
Harmonisation of effective levy to 0.5 ct/kWh	Unclear	Positive impact	Limited impact for the vast majority of C/S, moderate positive impact in 4 C/S, high positive impact in 3 C/S
Harmonisation of effective levies to 1 ct/kWh	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate positive impact in 1, high positive impact in 3 and moderate negative impact in 4 C/S
Harmonisation of effective levies to 1.5 ct/kWh	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate positive impact in 2, high positive impact in 1, moderate negative impact in 11 C/S and high negative impact in 3 C/S
Harmonisation of effective levies to 2 ct/kWh	Mostly positive impact	Positive impact	Limited impact for the majority of C/S, moderate positive impact in one, high positive impact in one, moderate negative impact in 22 and high negative impact in 6 C/S
Cond. ex. with TH of 1 ct/kWh and 75% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 2 and high negative impact in 1 country/sector
Cond. ex. with TH of 1 ct/kWh and 75% ex. on full levy-1ct	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 7 and high negative impact in 1 country/sector
Cond. ex. with TH of 1 ct/kWh and 85% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in only 1 country/sector
Cond. ex. with TH of 1 ct/kWh and 85% ex. on full levy-1ct	Mostly positive impact	Positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 4 and high negative in 1 country/sector
Cond. ex. with TH of 2 ct/kWh and 75% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 5 and high negative in 2 C/S
Cond. ex. with TH of 2 ct/kWh and 75% ex. on full levy-2ct	Mostly positive impact	Positive impact	Limited impact for the majority of C/S, moderate negative impact in 11 and high negative in 5 C/S
Cond. ex. with TH of 2 ct/kWh and 85% ex. on full levy	Mostly positive impact	Mostly positive impact	Limited impact for the vast majority of C/S, moderate negative impact in 4 and high negative in 1 country/sector
Cond. ex. with TH of 2 ct/kWh and 85% ex.on full levy-2ct	Mostly positive impact	Positive impact	Limited impact for the majority of C/S, moderate negative impact in 11 and high negative in 3 C/S

Source: Own calculations based on data from Amadeus, Eurostat and the European Commission. All scenarios assume changes of effective levies. Not all sectors are present in every Member State of the EU-11. The nine sectors in the EU-11 add up to 99 country-sectors, but only 81 country-sectors had information available on electricity consumption and levies. The delineation of impacts is into three categories: limited (changes in profits between zero and five percent), moderate (five and ten percent), or high (higher than ten percent). These specific thresholds should only be taken as an example for a possible quantification of the effects. See Section 3.5.2 for more details on the scenarios.

Annex 19 Detailed results of turnover coverage, average RES and CHP levies with and without reductions and detailed sectoral results from the simulation model per sector

Detailed results for each sector provided by this annex covers EU-11 countries and years, for which effective levy data is available. The following table presents the share of turnover, which is taken into account.

Table 61: Turnover coverage for descriptive analysis per sector

NACE Rev.2 sector name	Share in EU-11	Share in EU-14	Share in EU-27
Non-wovens (C13.95)	93	60	51
Veneer sheets (C16.21)	48	12	11
Pulp (C17.11)	96	77	58
Sanitary goods (C17.22)	94	91	19
Industrial gases (C20.11)	97	66	48
Inorganic chemicals (C20.13)	100	85	56
Iron and steel (C24.10)	100	72	50
Aluminium (C24.42)	98	79	60
Copper (C24.44)	98	81	54
Data processing (J63.11)	99	64	50

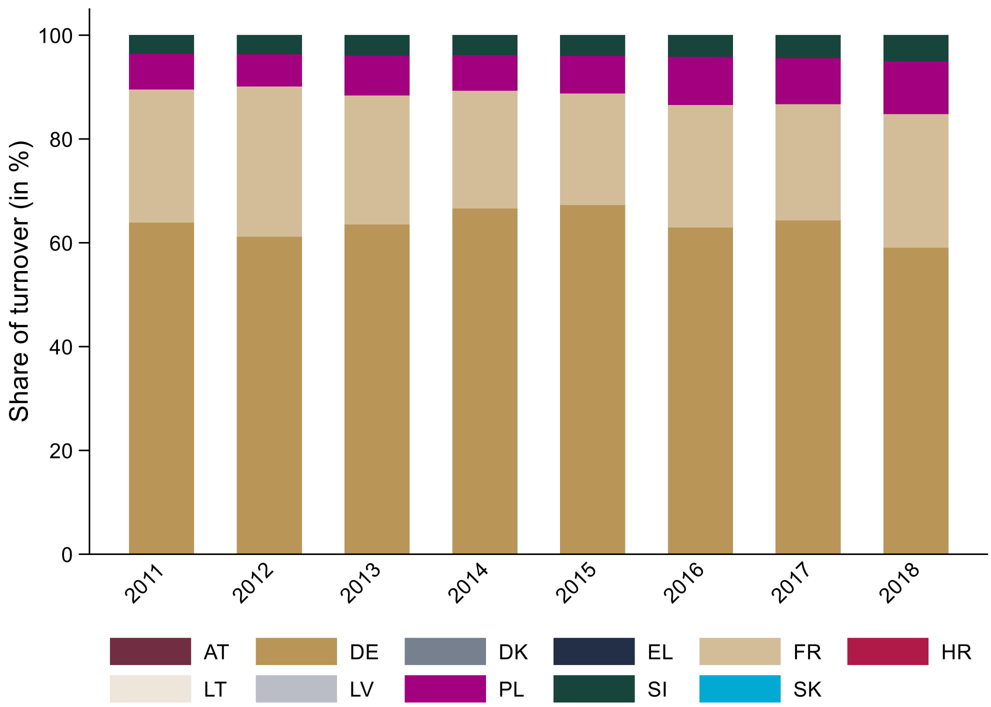
Source: Eurostat, European Commission and own calculations.

Within the EU-11 countries, we capture the vast majority of the sector's turnover. After including Estonia, Italy and Romania, for which electricity consumption data was not available, the EU-14 turnover coverage drops strongly in veneer sheets, and quite significantly in non-wovens, industrial gases and data processing. These sectors could be covered significantly better, if additional information on electricity consumption was made available for Estonia, Italy and Romania. Looking at the EU-27, about a half of turnover in most of sector is represented in the analysis (veneer sheets and sanitary goods being the exceptions with much lower shares).

Annex 19.1 Manufacture of non-wovens and articles made from non-wovens, except apparel

"Manufacture of non-wovens and articles made from non-wovens, except apparel" (NACE C13.95) is the sector located mainly in Germany, France, Poland and Slovenia within the EU-11 countries. The following chart depicts the share in the sector's EU-11 annual turnover shares for each country.

Figure 63: Share of EU-11 turnover by country for manufacture of non-wovens and articles made from non-wovens, except apparel



Source: Eurostat.

The sector is listed in Annex 3 of the EEAG. Electricity is the main energy source in nonwoven industry.[352] It has the EU-11 average electro-intensity of 11.6%. There were no studies available, which would allow assessing the plausibility of this estimate. A firm with the country-specific sector's average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in France and Poland, but was not eligible in Germany or Slovenia. The degree of pass-on of cost increase indicated by sector fiche was high[353] and we quantified it as 0.75. There are six other sectors in the same 3-digit NACE sector C13.9:

- Manufacture of cordage, rope, twine and netting (C13.94, listed in Annex 3 of the EEAG);
- Manufacture of knitted and crocheted fabrics (C13.91, listed in Annex 5 of the EEAG);
- Manufacture of made-up textile articles, except apparel (C13.92, listed in Annex 5 of the EEAG);
- Manufacture of carpets and rugs (C13.93, listed in Annex 5 of the EEAG);
- Manufacture of other technical and industrial textiles (C13.96, listed in Annex 5 of the EEAG);
- Manufacture of other textiles n.e.c. (C13.99, listed in Annex 5 of the EEAG).

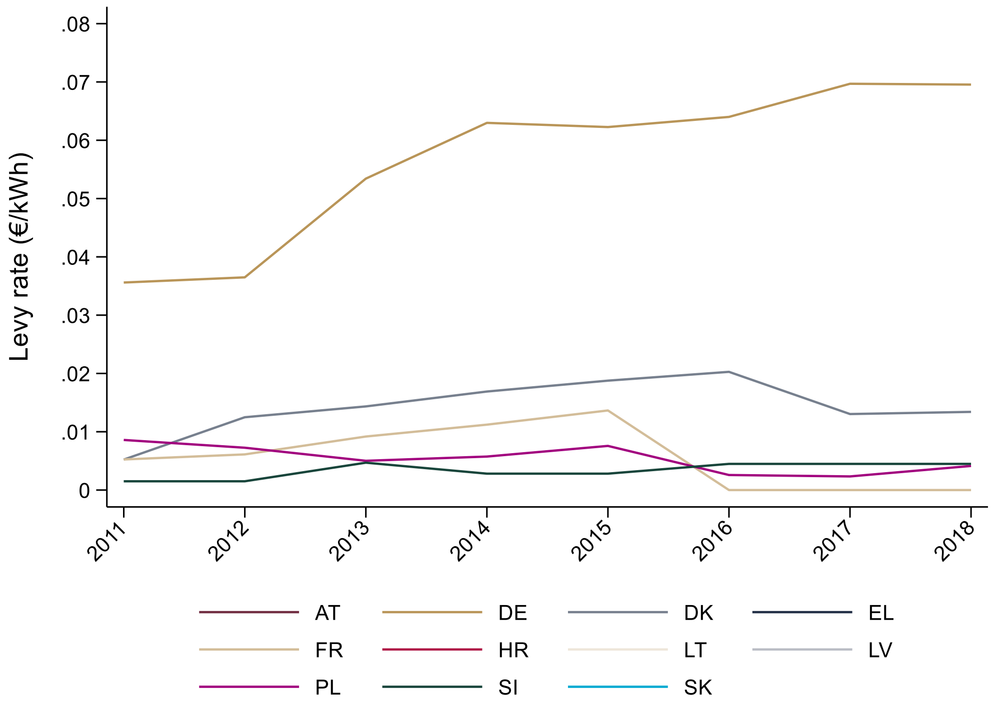
Annex 19.1.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of non-wovens and articles made from non-wovens, except apparel, were calculated over time before deducting the exemptions (levies without reduction) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levies per country.

[352] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of non-wovens and articles made from non-wovens, except apparel.

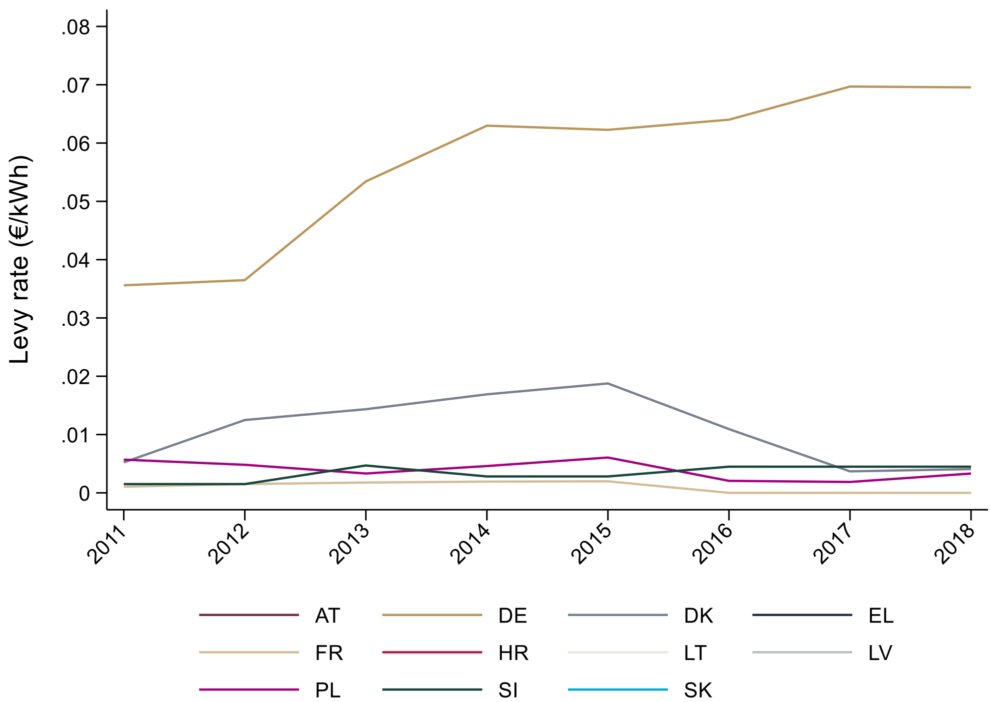
[353] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of non-wovens and articles made from non-wovens, except apparel.

Figure 64: RES and CHP levies without reductions in the manufacture of non-wovens and articles made from non-wovens, except apparel



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 65: RES and CHP effective levies in the manufacture of non-wovens and articles made from non-wovens, except apparel

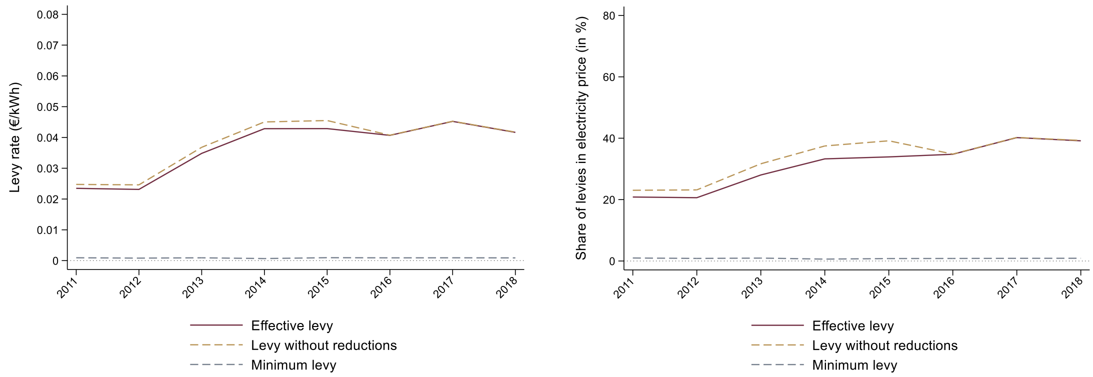


Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

The average firm in this sector pays the lowest levy in Slovenia (2011, 2012) and the exemptions bring the levy in France to the lowest level in the EU-11 as of 2013. The highest levy is paid in Germany, where the average firm does not benefit from exemptions.

The following figure presents the development of the EU-11 average RES and CHP levy without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 66: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of non-wovens and articles made from non-wovens, except apparel

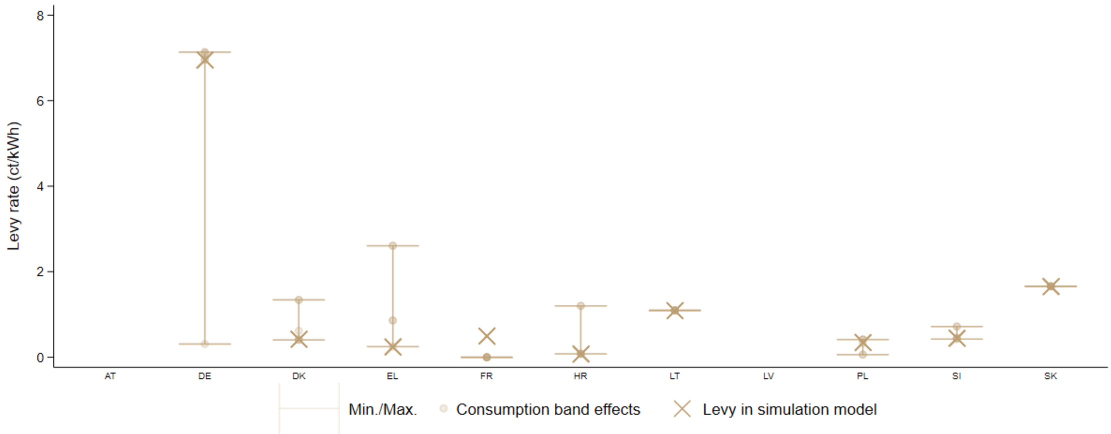


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 average RES and CHP levy stayed at a relatively high level above 0.02 €/kWh and it increased over time. The EU-11 average share of the levy in the electricity price increased from about 20% to more than a half. These developments reflect high levels of levies in Germany, which does not grant exemptions and has a high turnover share in the sector considered.

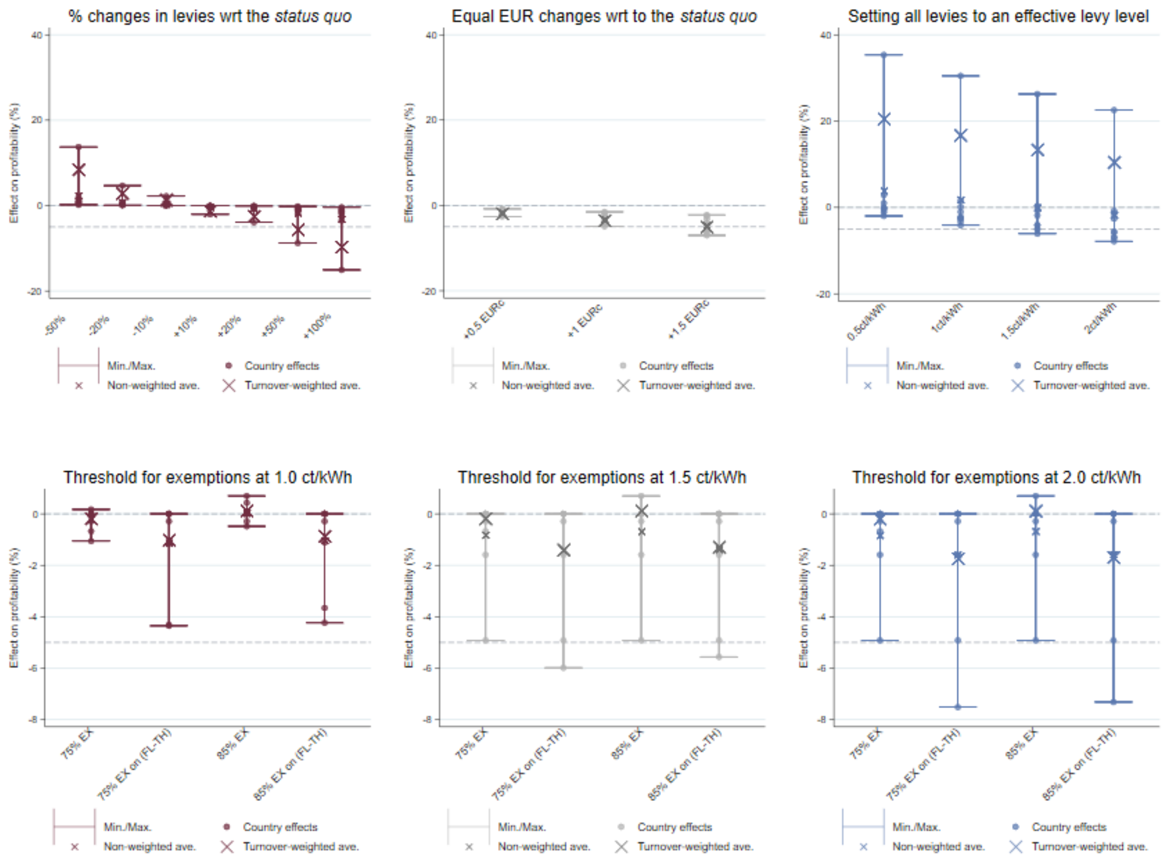
Annex 19.1.2 Detailed sectoral results from simulation model

Figure 67: Effective levy rate in 2018 per consumption band in non-wovens



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 68: Simulated profitability changes (%) per scenario for non-wovens



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 62: Simulated EU-11 average profitability changes (in %) for non-wovens

	Experi-ment	**Average non-weighted**	**Average turnover-weighted**	**Minimum effect across countries**	**Maximum effect across countries**
Unexempted levy or highest levy	Highest sector-specific levy	-13.2	-7.9	-21.0	0.0
	No exemptions	-1.7	-2.1	-8.9	0.0
% Changes to levies	-50%	2.3	8.5	0.2	13.7
	-20%	0.8	2.9	0.1	4.7
	-10%	0.4	1.4	0.0	2.2
	+10%	-0.4	-1.3	-2.0	0.0
	+20%	-0.7	-2.5	-3.9	-0.1
	+50%	-1.7	-5.6	-8.8	-0.2
	+100%	-3.1	-9.6	-15.0	-0.4
Absolute changes in levies	+0.5 ct	-1.7	-1.8	-2.6	-0.8
	+1.0 ct	-3.3	-3.5	-4.9	-1.5
	+1.5 ct	-4.7	-5.0	-7.0	-2.2

Setting the effective levy	0.5ct	3.9	20.5	-2.0	35.3
	1ct	1.9	16.7	-4.1	30.5
	1.5ct	0.0	13.4	-6.1	26.3
	2ct	-1.7	10.5	-7.8	22.6
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.2	-0.2	-1.1	0.2
	75% ex on amount above TH	-1.1	-1.0	-4.3	0.0
	85% ex on full levy	0.0	0.1	-0.5	0.7
	85% ex on amount above TH	-1.0	-0.9	-4.2	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.8	-0.2	-4.9	0.0
	75% ex on amount above TH	-1.4	-1.4	-6.0	0.0
	85% ex on full levy	-0.7	0.1	-4.9	0.7
	85% ex on amount above TH	-1.4	-1.3	-5.6	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-0.8	-0.2	-4.9	0.0
	75% ex on amount above TH	-1.6	-1.7	-7.5	0.0
	85% ex on full levy	-0.7	0.1	-4.9	0.7
	85% ex on amount above TH	-1.6	-1.7	-7.3	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 63: Simulated average profitability changes (in %) for non-wovens by country

Exp	**AT**	**DE**	**DK**	**EL**	**FR**	**HR**	**LT**	**LV**	**PL**	**SI**	**SK**
HI		0.0	-8.2	-19.6	-21.0	-20.1	-7.0		-16.6	-17.4	-9.4
No EX		0.0	-1.6	0.0	-8.9	-4.9	0.0		-0.3	0.0	0.0
-50%		13.7	0.4	0.6	1.4	0.2	0.9		0.7	1.0	2.0
-20%		4.7	0.2	0.2	0.6	0.1	0.4		0.3	0.4	0.8
-10%		2.2	0.1	0.1	0.3	0.0	0.2		0.1	0.2	0.4
+10%		-2.0	-0.1	-0.1	-0.3	0.0	-0.2		-0.1	-0.2	-0.4
+20%		-3.9	-0.2	-0.2	-0.5	-0.1	-0.4		-0.3	-0.4	-0.8

+50%	-8.8	-0.4	-0.6	-1.3	-0.2	-0.9		-0.6	-0.9	-1.8
+100%	-15.0	-0.8	-1.1	-2.6	-0.4	-1.7		-1.3	-1.9	-3.5
+0.5 ct	-1.5	-0.9	-2.2	-2.6	-2.3	-0.8		-1.8	-2.1	-1.1
+1.0 ct	-2.9	-1.7	-4.2	-4.9	-4.4	-1.5		-3.5	-3.9	-2.2
+1.5 ct	-4.2	-2.5	-6.0	-7.0	-6.4	-2.2		-5.1	-5.6	-3.2
0.5ct (eff. l.)	35.3	-0.1	-1.1	0.0	-2.0	1.0		-0.6	-0.2	2.9
1ct (eff. l.)	30.5	-1.0	-3.2	-2.6	-4.1	0.2		-2.4	-2.3	1.6
1.5ct (eff. l.)	26.3	-1.8	-5.1	-4.9	-6.1	-0.6		-4.0	-4.1	0.4
2ct (eff. l.)	22.6	-2.6	-6.9	-7.0	-7.8	-1.4		-5.6	-5.8	-0.8
75% ex (1ct)	0.0	0.2	0.0	-0.7	-1.1	0.0		-0.3	0.0	0.0
75% ex cond. (1ct)	0.0	-1.2	0.0	-4.3	-4.3	0.0		-0.3	0.0	0.0
85% ex (1ct)	0.0	0.4	0.0	0.7	-0.5	0.0		-0.3	0.0	0.0
85% ex cond. (1ct)	0.0	-1.1	0.0	-3.7	-4.2	0.0		-0.3	0.0	0.0
75% ex (1.5ct)	0.0	-1.6	0.0	-0.7	-4.9	0.0		-0.3	0.0	0.0
75% ex cond. (1.5ct)	0.0	-1.6	0.0	-6.0	-4.9	0.0		-0.3	0.0	0.0
85% ex (1.5ct)	0.0	-1.6	0.0	0.7	-4.9	0.0		-0.3	0.0	0.0
85% ex cond. (1.5ct)	0.0	-1.6	0.0	-5.6	-4.9	0.0		-0.3	0.0	0.0
75% ex (2ct)	0.0	-1.6	0.0	-0.7	-4.9	0.0		-0.3	0.0	0.0
75% ex cond. (2ct)	0.0	-1.6	0.0	-7.5	-4.9	0.0		-0.3	0.0	0.0
85% ex (2ct)	0.0	-1.6	0.0	0.7	-4.9	0.0		-0.3	0.0	0.0
85% ex cond. (2ct)	0.0	-1.6	0.0	-7.3	-4.9	0.0		-0.3	0.0	0.0
Turnover (M. euro)	1672		112	649	5	24		257	126	25

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.2 Manufacture of veneer sheers and wood-based panels

"Manufacture of veneer sheets and wood-based panels" (NACE C16.21) is a sector located mainly in Germany, Austria, France, Poland and a few smaller countries: Denmark, Greece, Lithuania, Latvia, Slovenia and Slovakia, out of the EU-11 countries. The following chart depicts annual turnover shares by country.

Figure 69: Share of EU-11 turnover by country for manufacture of veneer sheets and wood-based panels

Source: Eurostat.

The sector is listed in Annex 3 of the EEAG. It has the average electro-intensity of 20.78%. There were no studies available, which would allow to assess the plausibility of this estimate. A firm with the country-specific sector's average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Denmark, Germany, France, Poland and Slovenia. The degree of pass-on of cost increase indicated by the sector fiche was low[354] and we quantified it with 0.25. Other sectors from the same 3-digit NACE C16.2 sector are:

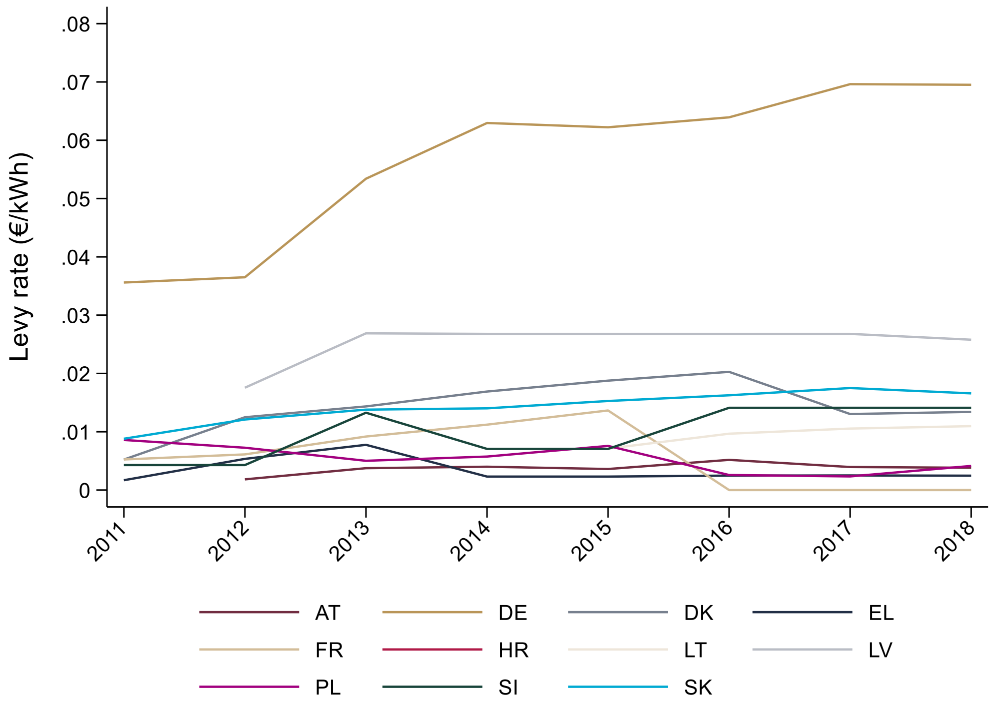
- Manufacture of assembled parquet floors (C16.22, listed in Annex 5 of the EEAG);
- Manufacture of other builders' carpentry and joinery (C16.23, listed in Annex 5 of the EEAG);
- Manufacture of wooden containers (C16.24, listed in Annex 5 of the EEAG);
- Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials (C16.29, listed in Annex 5 of the EEAG).

Annex 19.2.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of veneer sheets and wood-based panels were calculated over time before deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levy types per country.

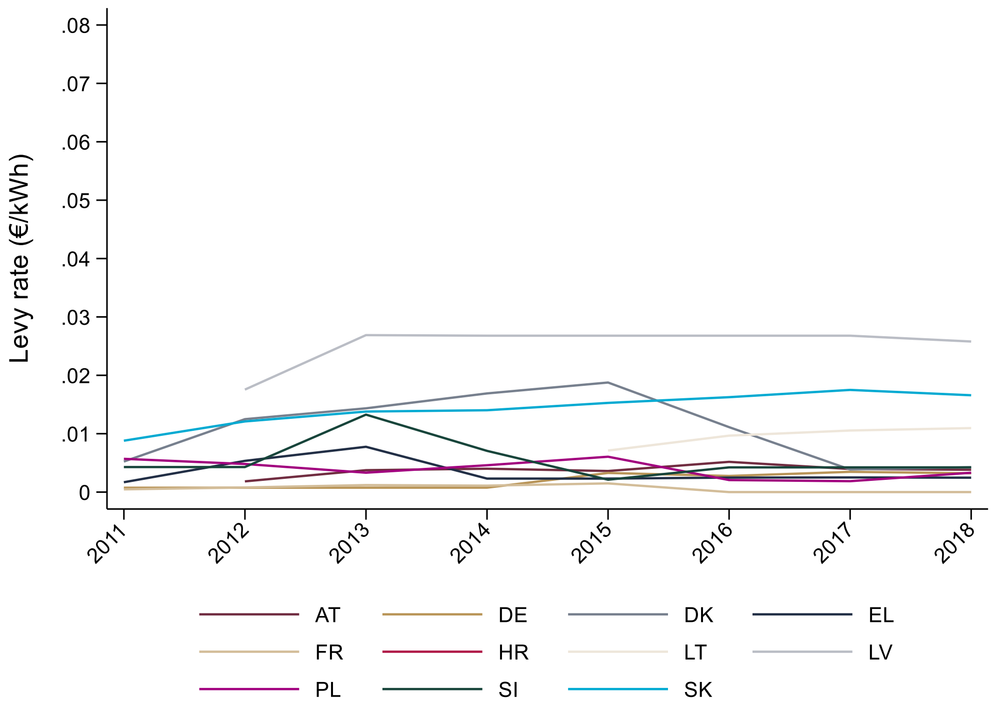
[354] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of veneer sheets and wood-based panels.

Figure 70: RES and CHP levies without reductions in the manufacture of veneer sheets and wood-based panels



Source: Support study. European Commission, Eurostat, and own calculations.

Figure 71: RES and CHP effective levies in the manufacture of veneer sheets and wood-based panels

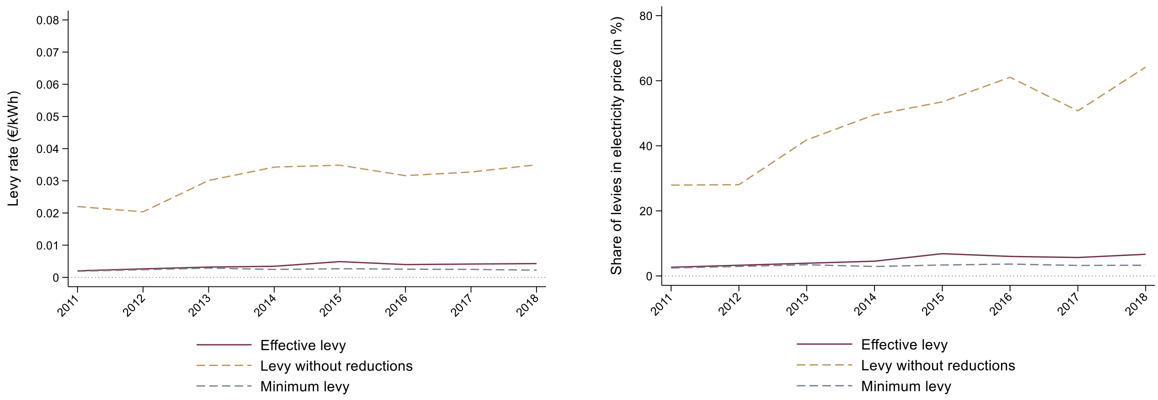


Source: Support study. European Commission, Eurostat, and own calculations.

Comparing the levy for Germany in the above two figures, it is clear that the exemptions bring the levy in Germany to the level similar to other EU-11 countries. The highest levy without reductions is in Germany in every year, but the highest effective levy is in Denmark (2012-2015) and Slovakia (2011 and 2016-2018). The lowest levies without exemptions are paid in Austria, France and Greece, for effective levies it is Germany, Greece and France.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 72: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of veneer sheets and wood-based panels

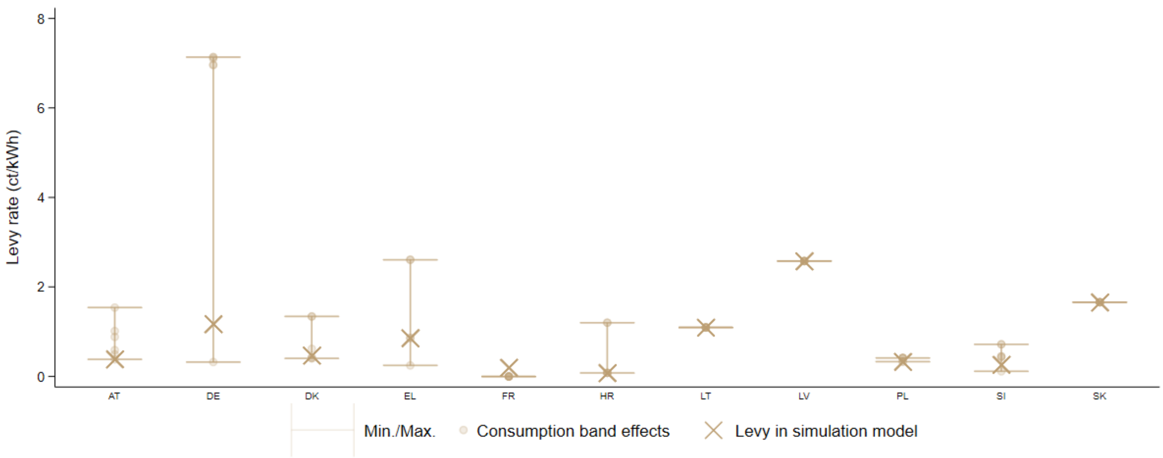


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 average RES and CHP effective levy increased significantly from about 0 to 0.01 €/kWh. The EU-11 average share of the effective levy in the electricity price increased to about 10% with an upward shift in 2014.

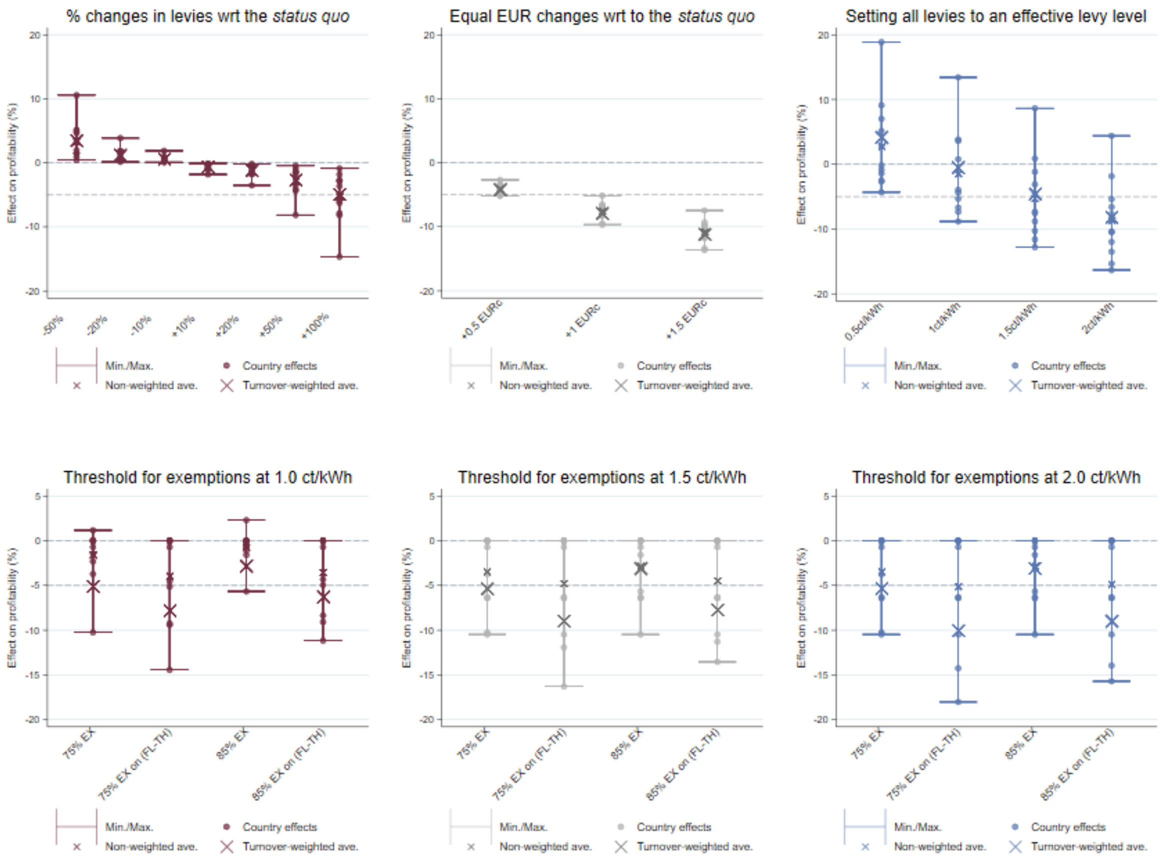
Annex 19.2.2 Detailed sectoral results from simulation model

Figure 73: Effective levy rate in 2018 per consumption band in veneer sheets



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 74: Simulated profitability changes (%) per scenario for veneer sheets



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 64: Simulated EU-11 average profitability changes (in %) for veneer sheets

	Experi-ment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or high-est levy	Highest sector-specific levy	-30.4	-30.8	-38.2	-21.1
	No exemp-tions	-6.4	-15.7	-30.4	0.0
% Changes to levies	-50%	3.3	3.5	0.4	10.6
	-20%	1.2	1.3	0.2	3.9
	-10%	0.6	0.6	0.1	1.9
	+10%	-0.6	-0.6	-1.8	-0.1
	+20%	-1.2	-1.1	-3.5	-0.2
	+50%	-2.8	-2.6	-8.1	-0.4
	+100%	-5.2	-4.8	-14.7	-0.9
	+0.5 ct	-4.0	-4.2	-5.2	-2.7
	+1.0 ct	-7.6	-7.8	-9.7	-5.1

Absolute changes in levies	+1.5 ct	-10.8	-11.2	-13.6	-7.5
Setting the effective levy	0.5ct	2.8	4.2	-4.3	18.9
	1ct	-1.4	-0.4	-8.8	13.4
	1.5ct	-5.2	-4.5	-12.8	8.6
	2ct	-8.6	-8.2	-16.3	4.4
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-1.6	-5.1	-10.2	1.2
	75% ex on amount above TH	-4.0	-7.8	-14.4	0.0
	85% ex on full levy	-0.7	-2.8	-5.7	2.3
	85% ex on amount above TH	-3.5	-6.2	-11.2	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-3.4	-5.3	-10.5	0.0
	75% ex on amount above TH	-4.7	-9.0	-16.3	0.0
	85% ex on full levy	-2.8	-3.1	-10.5	0.0
	85% ex on amount above TH	-4.4	-7.7	-13.5	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-3.4	-5.3	-10.5	0.0
	75% ex on amount above TH	-5.1	-10.0	-18.0	0.0
	85% ex on full levy	-2.8	-3.1	-10.5	0.0
	85% ex on amount above TH	-4.9	-9.0	-15.7	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 65: Simulated average profitability changes (in %) for veneer sheets by country

Exp	**AT**	**DE**	**DK**	**EL**	**FR**	**HR**	**LT**	**LV**	**PL**	**SI**	**SK**
HI	-29.7	-30.4	-30.7	-29.1	-33.9	-38.1	-28.8	-21.9	-32.5	-38.2	-21.1
No EX	0.0	-30.4	-6.3	0.0	-16.4	-10.5	0.0	0.0	-0.7	-6.4	0.0
-50%	1.5	5.2	2.0	3.3	0.9	0.4	4.7	10.6	1.4	1.5	4.9
-20%	0.6	1.8	0.8	1.3	0.4	0.2	1.8	3.9	0.6	0.6	1.9
-10%	0.3	0.9	0.4	0.6	0.2	0.1	0.9	1.9	0.3	0.3	0.9

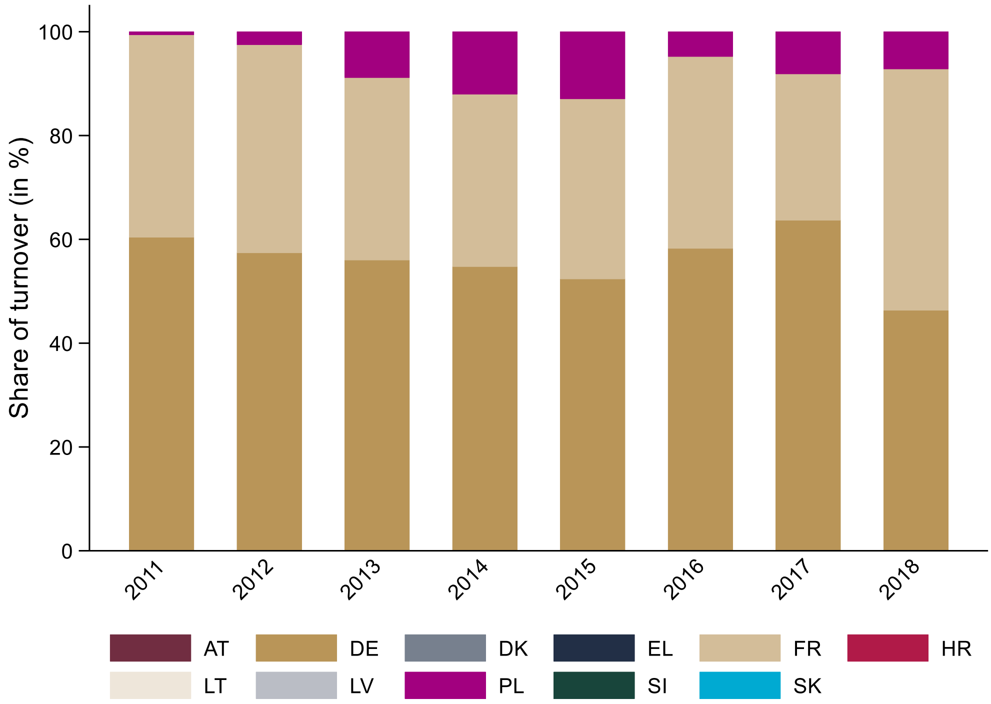
+10%	-0.3	-0.8	-0.4	-0.6	-0.2	-0.1	-0.9	-1.8	-0.3	-0.3	-0.9
+20%	-0.6	-1.5	-0.8	-1.3	-0.4	-0.2	-1.7	-3.5	-0.6	-0.6	-1.8
+50%	-1.4	-3.5	-1.9	-3.1	-0.9	-0.4	-4.1	-8.1	-1.4	-1.4	-4.3
+100%	-2.8	-6.2	-3.6	-5.9	-1.8	-0.9	-7.8	-14.7	-2.7	-2.8	-8.2
+0.5 ct	-3.6	-4.4	-3.8	-3.6	-4.3	-5.1	-3.8	-3.4	-4.0	-5.2	-2.7
+1.0 ct	-6.8	-8.3	-7.2	-6.8	-8.2	-9.5	-7.2	-6.5	-7.7	-9.7	-5.1
+1.5 ct	-9.8	-11.8	-10.3	-9.8	-11.6	-13.4	-10.3	-9.3	-10.9	-13.6	-7.5
0.5ct (eff. l.)	-0.8	9.1	-0.2	2.8	-2.7	-4.3	5.1	18.9	-1.4	-2.5	7.0
1ct (eff. l.)	-4.4	3.6	-3.9	-1.0	-6.7	-8.8	0.8	13.4	-5.3	-7.3	3.8
1.5ct (eff. l.)	-7.5	-1.2	-7.3	-4.5	-10.3	-12.8	-3.1	8.6	-8.8	-11.6	0.9
2ct (eff. l.)	-10.4	-5.4	-10.4	-7.7	-13.5	-16.3	-6.6	4.4	-12.0	-15.4	-1.8
75% ex (1ct)	0.0	-10.2	1.2	0.0	-3.7	-2.3	0.0	0.0	-0.7	-1.4	0.0
75% ex cond. (1ct)	0.0	-14.4	-4.5	0.0	-9.4	-9.2	0.0	0.0	-0.7	-5.1	0.0
85% ex (1ct)	0.0	-5.7	2.3	0.0	-1.6	-1.1	0.0	0.0	-0.7	-0.6	0.0
85% ex cond. (1ct)	0.0	-11.2	-4.3	0.0	-8.4	-9.1	0.0	0.0	-0.7	-4.9	0.0
75% ex (1.5ct)	0.0	-10.2	-6.3	0.0	-3.7	-10.5	0.0	0.0	-0.7	-6.4	0.0
75% ex cond. (1.5ct)	0.0	-16.3	-6.3	0.0	-11.9	-10.5	0.0	0.0	-0.7	-6.4	0.0
85% ex (1.5ct)	0.0	-5.7	-6.3	0.0	-1.6	-10.5	0.0	0.0	-0.7	-6.4	0.0
85% ex cond. (1.5ct)	0.0	-13.5	-6.3	0.0	-11.3	-10.5	0.0	0.0	-0.7	-6.4	0.0
75% ex (2ct)	0.0	-10.2	-6.3	0.0	-3.7	-10.5	0.0	0.0	-0.7	-6.4	0.0
75% ex cond. (2ct)	0.0	-18.0	-6.3	0.0	-14.2	-10.5	0.0	0.0	-0.7	-6.4	0.0
85% ex (2ct)	0.0	-5.7	-6.3	0.0	-1.6	-10.5	0.0	0.0	-0.7	-6.4	0.0
85% ex cond. (2ct)	0.0	-15.7	-6.3	0.0	-13.9	-10.5	0.0	0.0	-0.7	-6.4	0.0
Turnover (M. euro)	1570	5771	132	68	1596	141	159	535	2761	159	306

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.3 Manufacture of pulp

"Manufacture of pulp" (NACE C17.11) is a sector located in three of the EU-11 countries: Germany, France and Poland. The following chart depicts annual turnover shares by country.

Figure 75: Share of EU-11 turnover by country for manufacture of pulp



Source: Eurostat.

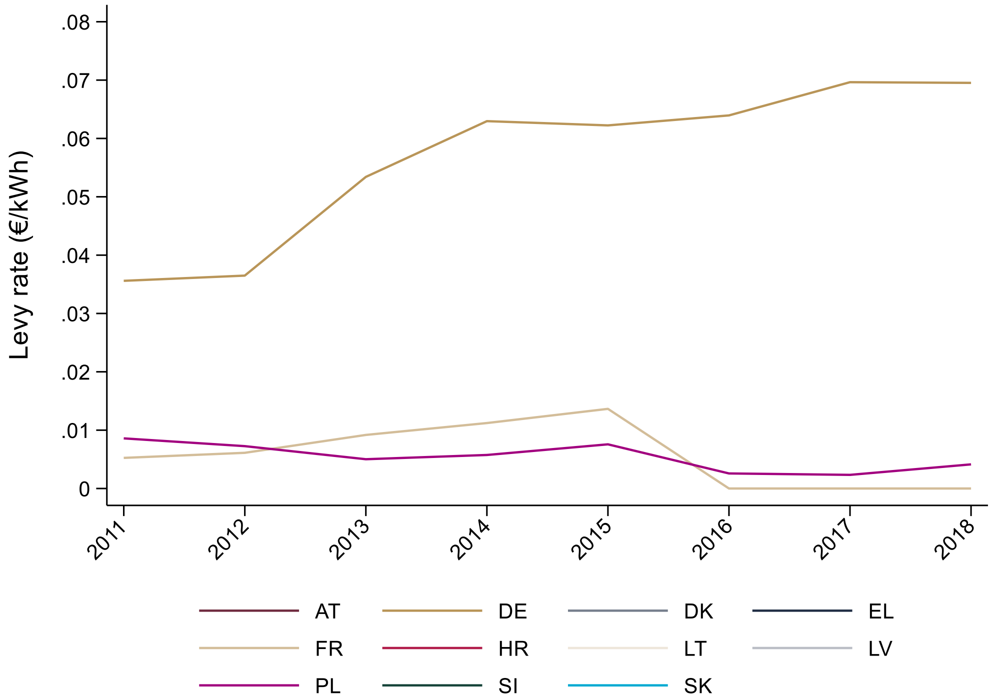
The sector is listed in Annex 3 of the EEAG. The pulp production is energy-intensive and partially sources electricity from self-generation in own CHP plants. Depending on the end-product, electricity consumption in each production process differs.[355] It has the EU-11 average electro-intensity of 34.72%. A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in all three counties. The degree of pass-on of cost increase which was indicated by the sector fiche was low[356] and we quantified it with 0.25. Another sector from the same 3-digit NACE sector C17.1 is manufacture of paper and paperboard (C17.12) also listed in Annex 3 of the EEAG.

Annex 19.3.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of pulp were calculated over time before deducting the exemptions (levy without reductions) and after deducting the exemptions (effective levy). The following figures depict the time-development of both levy types per country.

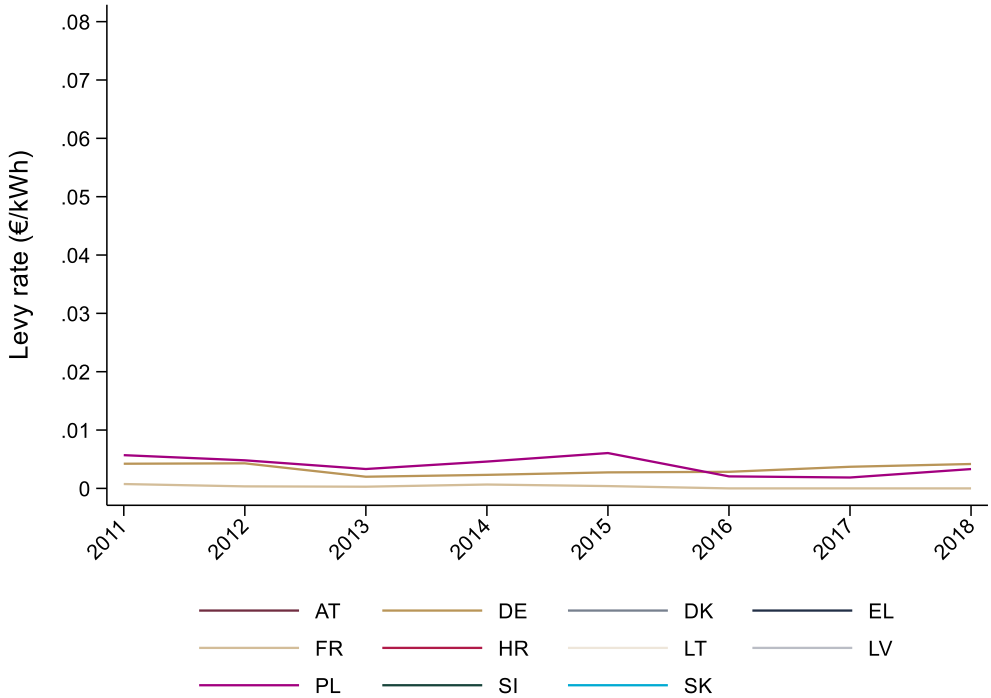
[355] "Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of pulp.
[356] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of pulp.

Figure 76: RES and CHP levies without reductions in the manufacture of pulp



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 77: RES and CHP effective levies in the manufacture of pulp



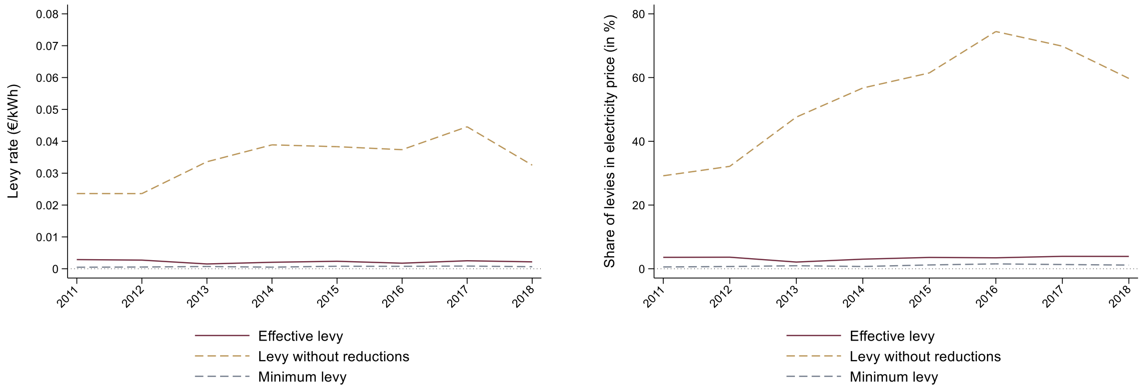
Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

The exemptions bring the levy in Germany to the levy range in the other countries. The highest levy without reductions is in Germany in the entire time period, but the effective levy is highest in Poland in the years 2011-2013 and in Germany in the years 2014-2018.

France features lowest levies in the entire time period, effective levies being matched by Germany 2012-2013 and the levies without reductions matched by Poland in 2013-2015.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 78: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of pulp

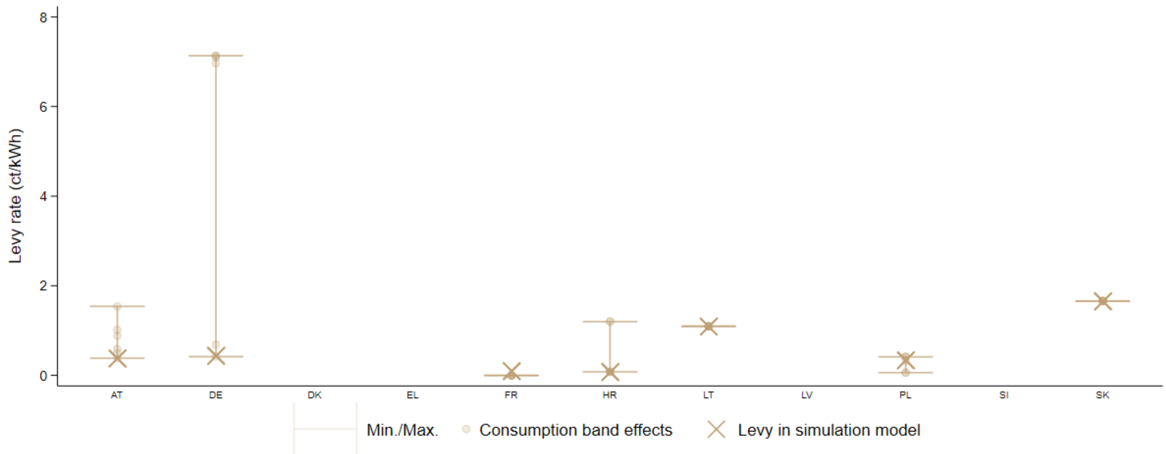


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 levies without reductions increase significantly from about 20% of electricity price in 2011 to almost 50% in 2017 and drop again in 2018. The exemptions reduce the paid levies very strongly to less than 10%. The effective levy increased over time with the most significant shift in 2014, which reflects the increase of effective levies in Germany.

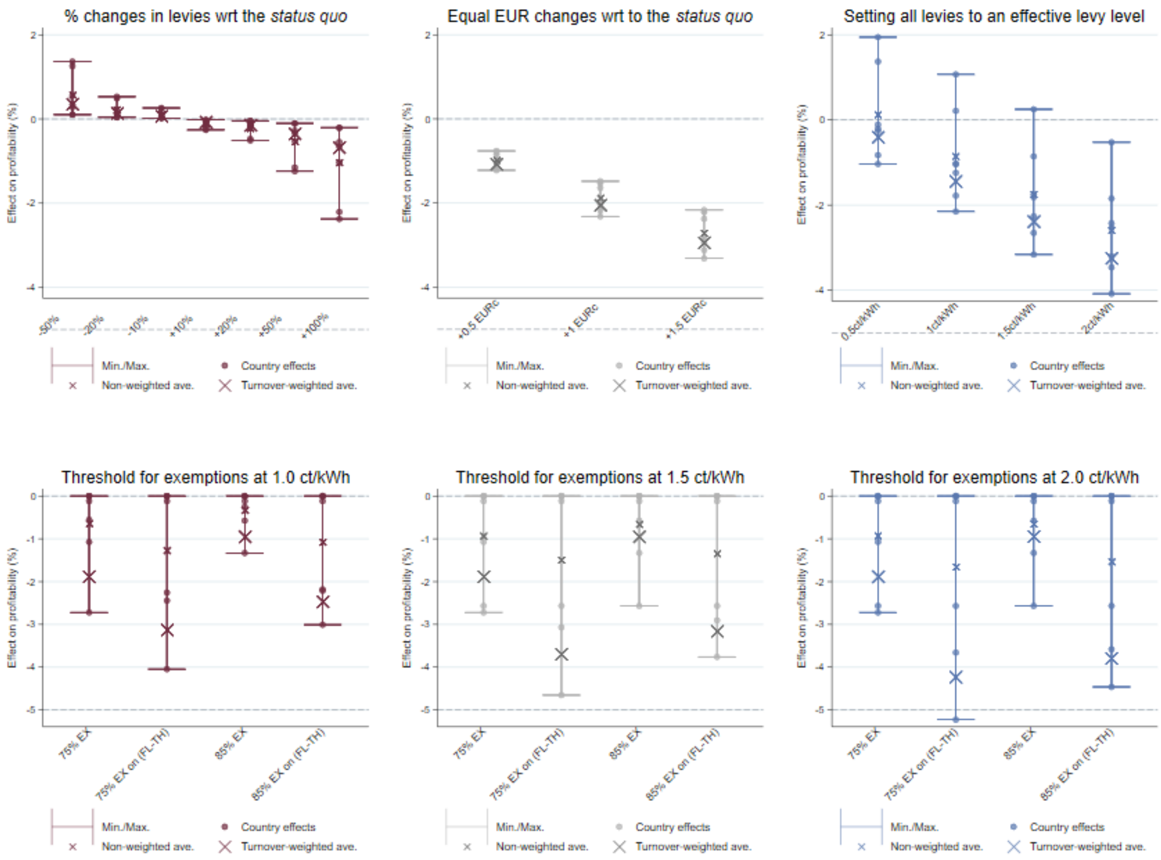
Annex 19.3.2 Detailed sectoral results from simulation model

Figure 79: Effective levy rate in 2018 per consumption band in pulp



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 80: Simulated profitability changes (%) per scenario for pulp



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 66: Simulated EU-11 average profitability changes (in %) for pulp

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-8.6	-9.3	-10.4	-6.4
	No exemptions	-2.4	-6.8	-9.7	0.0
% Changes to levies	-50%	0.6	0.4	0.1	1.4
	-20%	0.2	0.1	0.0	0.5
	-10%	0.1	0.1	0.0	0.3
	+10%	-0.1	-0.1	-0.3	0.0
	+20%	-0.2	-0.1	-0.5	0.0
	+50%	-0.5	-0.3	-1.2	-0.1
	+100%	-1.0	-0.7	-2.4	-0.2
Absolute changes in levies	+0.5 ct	-1.0	-1.1	-1.2	-0.8
	+1.0 ct	-1.9	-2.0	-2.3	-1.5
	+1.5 ct	-2.7	-2.9	-3.3	-2.2
Setting the effective levy	0.5ct	0.1	-0.4	-1.0	1.9
	1ct	-0.9	-1.4	-2.1	1.1
	1.5ct	-1.7	-2.4	-3.2	0.3
	2ct	-2.6	-3.2	-4.1	-0.5
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.6	-1.9	-2.7	0.0
	75% ex on amount above TH	-1.3	-3.1	-4.0	0.0
	85% ex on full levy	-0.3	-0.9	-1.3	0.0
	85% ex on amount above TH	-1.1	-2.5	-3.0	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.9	-1.9	-2.7	0.0
	75% ex on amount above TH	-1.5	-3.7	-4.7	0.0
	85% ex on full levy	-0.7	-0.9	-2.6	0.0
	85% ex on amount above TH	-1.3	-3.1	-3.8	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-0.9	-1.9	-2.7	0.0
	75% ex on amount above TH	-1.7	-4.2	-5.2	0.0

	85% ex on full levy	-0.7	-0.9	-2.6	0.0
	85% ex on amount above TH	-1.5	-3.8	-4.5	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Table 67: Simulated average profitability changes (in %) for pulp by country

Exp	**AT**	**DE**	**DK**	**EL**	**FR**	**HR**	**LT**	**LV**	**PL**	**SI**	**SK**
HI	-7.9	-9.7			-9.2	-10.4	-8.9		-7.5		-6.4
No EX	0.0	-9.7			-4.2	-2.6	0.0		-0.1		0.0
-50%	0.3	0.6			0.1	0.1	1.3		0.3		1.4
-20%	0.1	0.2			0.0	0.0	0.5		0.1		0.5
-10%	0.1	0.1			0.0	0.0	0.2		0.1		0.3
+10%	-0.1	-0.1			0.0	0.0	-0.2		-0.1		-0.3
+20%	-0.1	-0.2			0.0	0.0	-0.5		-0.1		-0.5
+50%	-0.3	-0.5			-0.1	-0.1	-1.1		-0.3		-1.2
+100%	-0.7	-1.0			-0.2	-0.2	-2.2		-0.5		-2.4
+0.5 ct	-0.9	-1.1			-1.0	-1.2	-1.1		-0.8		-0.8
+1.0 ct	-1.6	-2.2			-2.0	-2.3	-2.0		-1.5		-1.5
+1.5 ct	-2.4	-3.1			-2.8	-3.3	-2.9		-2.2		-2.2
0.5ct (eff. l.)	-0.2	-0.1			-0.8	-1.0	1.4		-0.3		1.9
1ct (eff. l.)	-1.0	-1.2			-1.8	-2.1	0.2		-1.0		1.1
1.5ct (eff. l.)	-1.8	-2.3			-2.7	-3.2	-0.9		-1.7		0.3
2ct (eff. l.)	-2.5	-3.2			-3.5	-4.1	-1.8		-2.4		-0.5
75% ex (1ct)	0.0	-2.7			-1.1	-0.6	0.0		-0.1		0.0
75% ex cond. (1ct)	0.0	-4.0			-2.4	-2.3	0.0		-0.1		0.0
85% ex (1ct)	0.0	-1.3			-0.6	-0.3	0.0		-0.1		0.0
85% ex cond. (1ct)	0.0	-3.0			-2.2	-2.2	0.0		-0.1		0.0
75% ex (1.5ct)	0.0	-2.7			-1.1	-2.6	0.0		-0.1		0.0
75% ex cond. (1.5ct)	0.0	-4.7			-3.1	-2.6	0.0		-0.1		0.0
85% ex (1.5ct)	0.0	-1.3			-0.6	-2.6	0.0		-0.1		0.0
85% ex cond. (1.5ct)	0.0	-3.8			-2.9	-2.6	0.0		-0.1		0.0

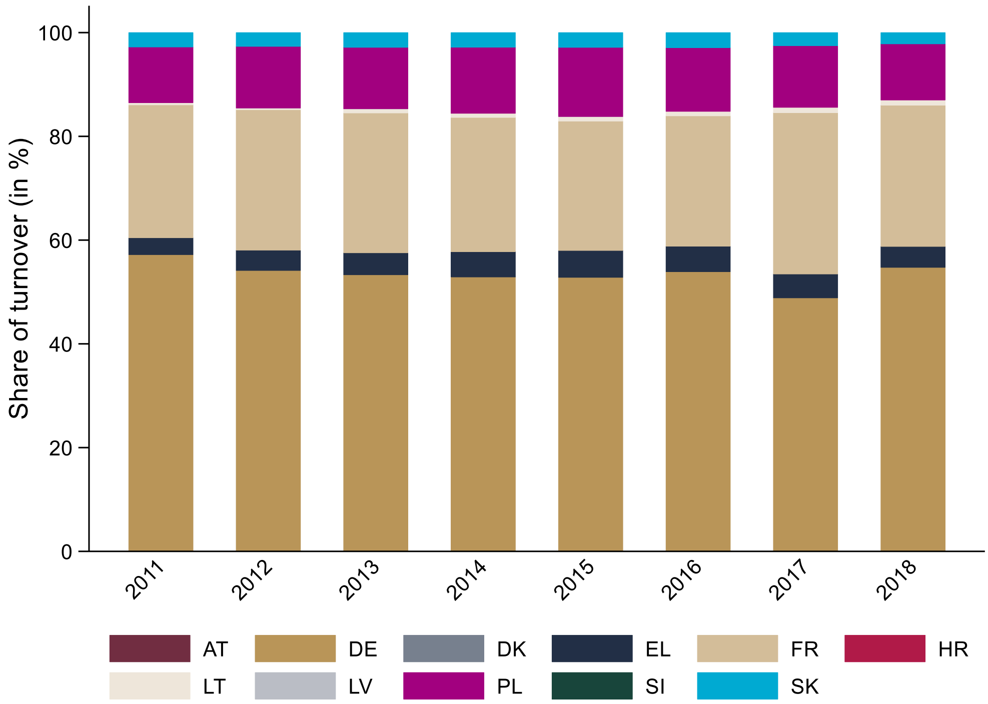
75% ex (2ct)	0.0	-2.7	-1.1	-2.6	0.0	-0.1	0.0
75% ex cond. (2ct)	0.0	-5.2	-3.7	-2.6	0.0	-0.1	0.0
85% ex (2ct)	0.0	-1.3	-0.6	-2.6	0.0	-0.1	0.0
85% ex cond. (2ct)	0.0	-4.5	-3.6	-2.6	0.0	-0.1	0.0
Turnover (M. euro)		1150	847			163	

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.4 Manufacture of household and sanitary goods and of toilet requisites

"Manufacture of household and sanitary goods and of toilet requisites" (NACE C17.22) is the sector located in 6 out of the EU-11 countries: Germany, France, Poland, Greece, Slovakia and Latvia. The following chart depicts annual turnover shares by country.

Figure 81: Share of EU-11 turnover by country for manufacture of household and sanitary goods and of toilet requisites



Source: *Eurostat.*

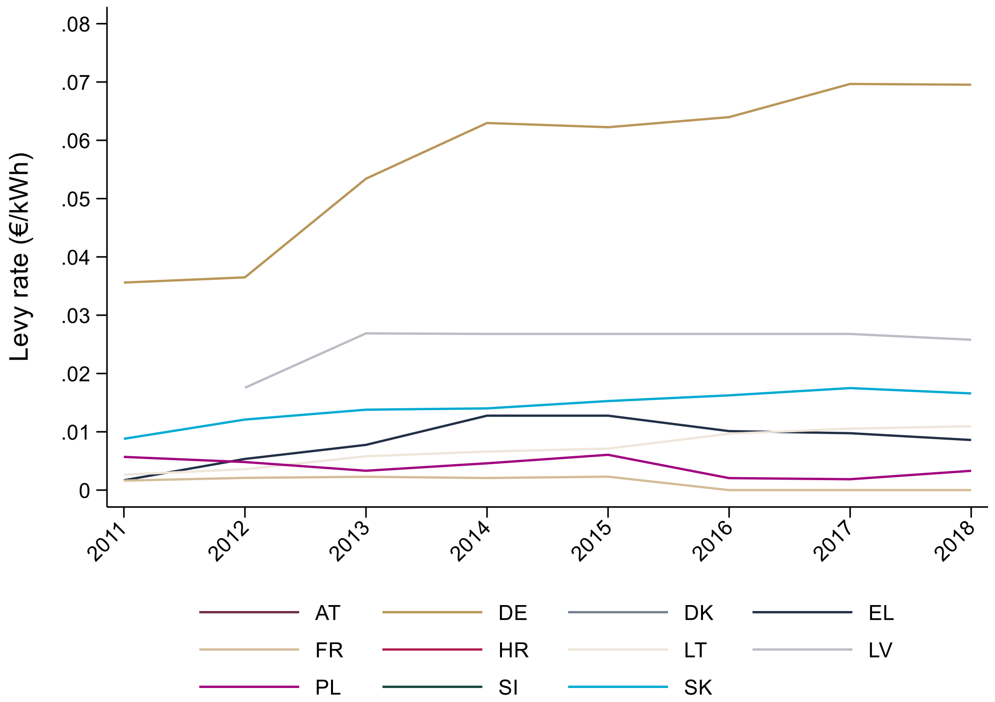
The sector is listed in Annex 3 of the EEAG. It has the EU-11 average electro-intensity of 10.87%. There were no studies available, which would allow to assess the plausibility of this figure. A firm with the country-specific sector's average electro-intensity and electricity consumption not eligible for RES and CHP levy exemptions in any of the above countries. We assess the degree of pass-on of cost increases as medium based on the following criteria: large number of active companies,[357] high trade value[358] and high heterogeneity of products. We quantified it with 0.5. There are four other sectors from the same 3-digit NACE sector C17.2:

- Manufacture of corrugated paper and paperboard and of containers of paper and paperboard (C17.21, listed in Annex 5 of the EEAG);
- Manufacture of paper stationery (C17.23, listed in Annex 5 of the EEAG);
- Manufacture of wallpaper (C17.24, listed in Annex 5 of the EEAG);
- Manufacture of other articles of paper and paperboard (17.29, listed in Annex 5 of the EEAG).

Annex 19.4.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of household and sanitary goods and of toilet requisites were calculated over time before deducting the exemptions (levies without reductions) after deducting the exemptions (effective levies). The following figures depict the time-development of both levies per country.

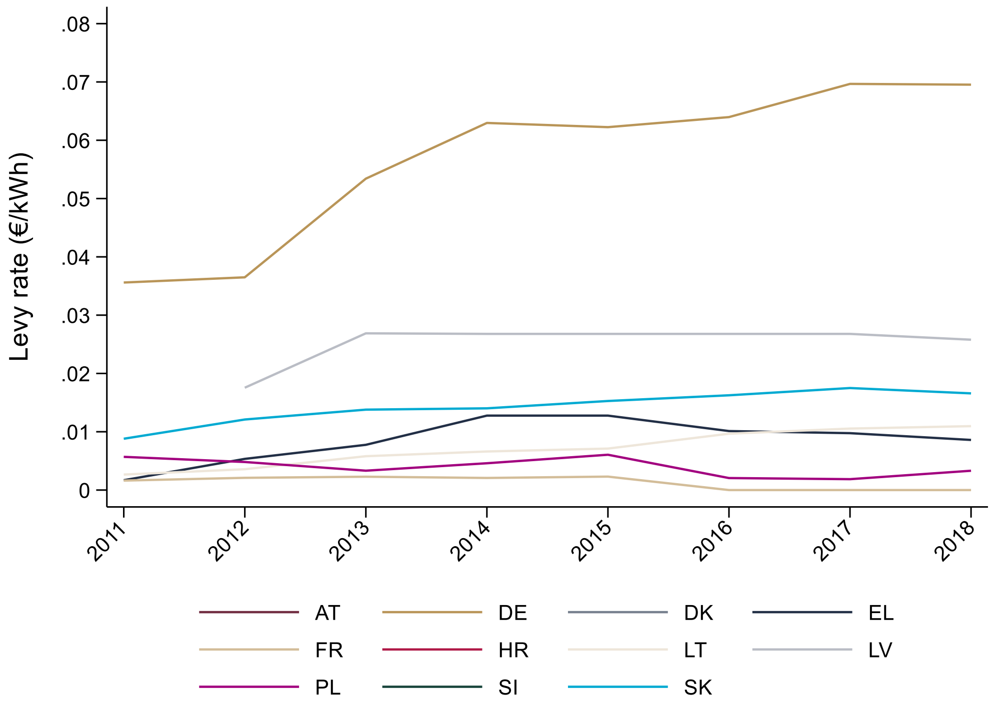
Figure 82: RES and CHP levies without reductions in the manufacture of household and sanitary goods and of toilet requisites the manufacture of pulp



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

[357] About 500 companies were active in EU-11 in this sector annually in the period 2011-2018 (SBS, Eurostat).
[358] The average annual export value over the years 2011-2018 is 510 Mio €. The average annual import value over the years 2011-2018 is 382 Mio € (Prodcom, Eurostat).

Figure 83: RES and CHP effective levies in the manufacture of household and sanitary goods and of toilet requisites

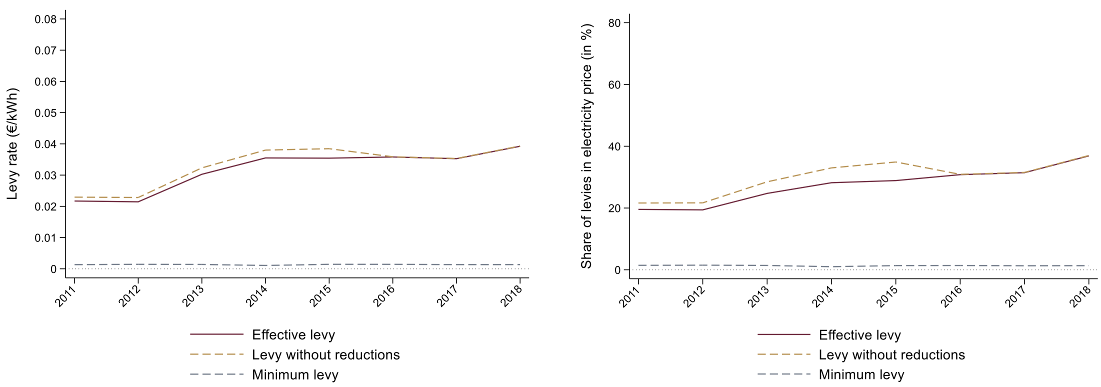


Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Levies without reductions were the same as effective levies, because the sector was not eligible for reductions. The effective levies in all three countries were very close in years 2011-2015. In 2016, the levy in France dropped to zero.

The following figure presents the development of the EU-11 average RES and CHP levy without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 84: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of household and sanitary goods and of toilet requisites

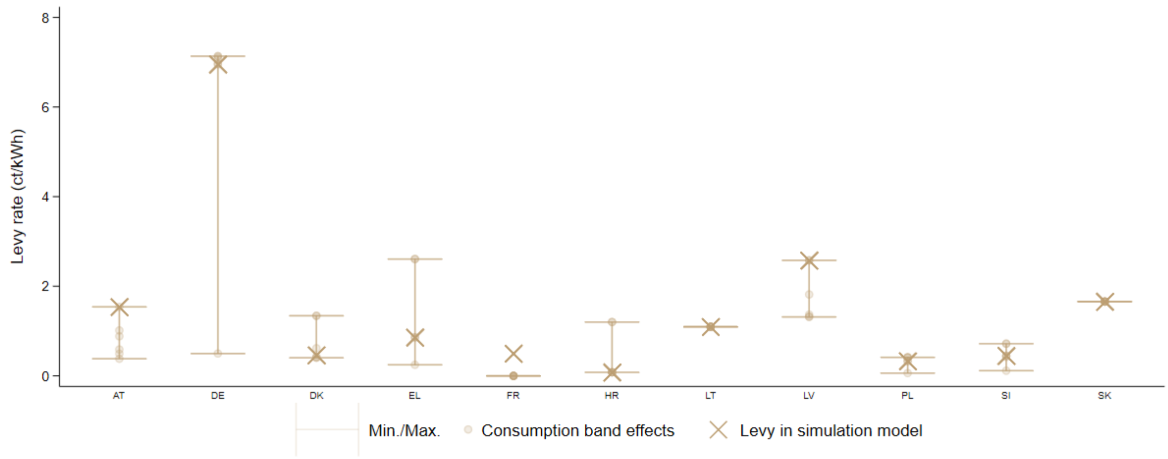


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 average RES and CHP levy increased slowly until 2015 and dropped to almost zero in 2016. The EU-11 average share of the levy in the electricity price was just above 10% and dropped to almost zero in 2016. These developments reflect the RES and CHP levy development for France, which stopped collecting RES and CHP levies in 2016 and has a high turnover share in the sector considered.

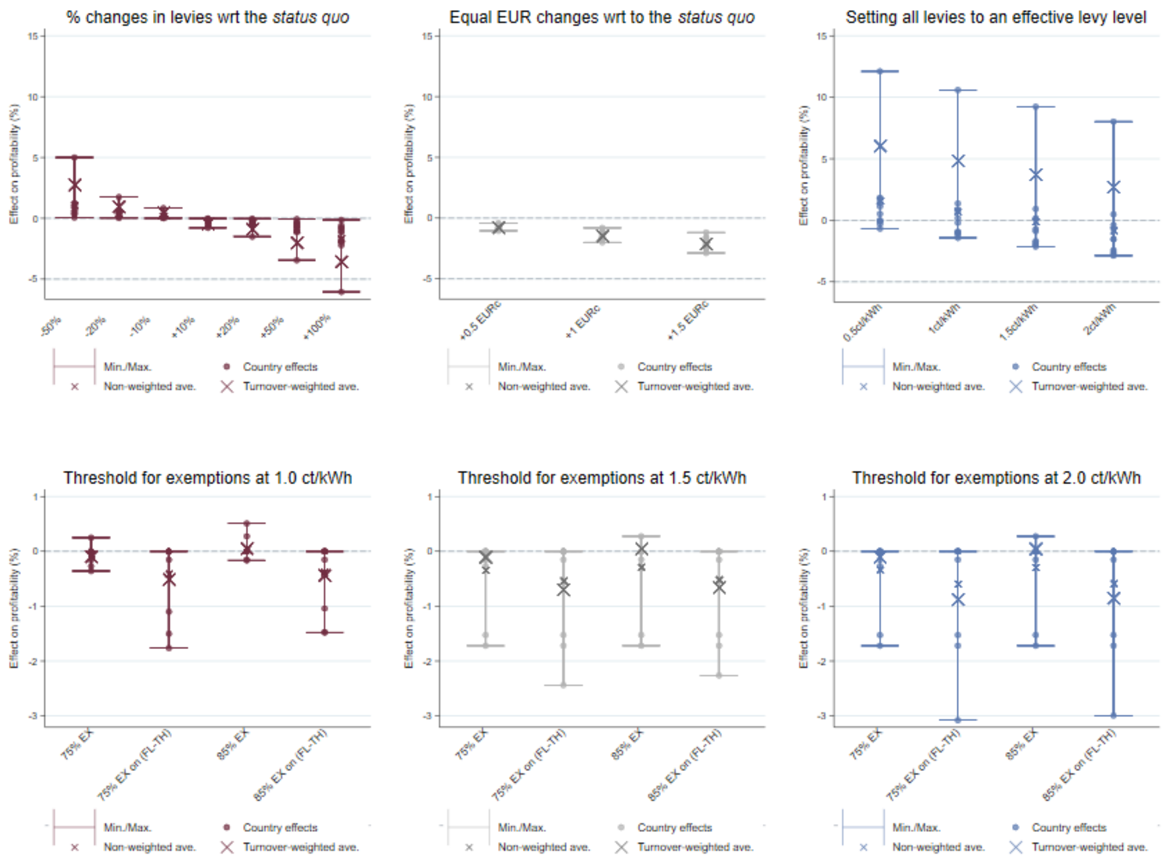
Annex 19.4.2 Detailed sectoral results from simulation model

Figure 85: Effective levy rate in 2018 per consumption band in sanitary goods



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 86: Simulated profitability changes (%) per scenario for sanitary goods



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 68: Simulated EU-11 average profitability changes (in %) for sanitary goods

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-6.4	-4.2	-9.0	0.0
	No exemptions	-0.6	-1.0	-3.7	0.0
% Changes to levies	-50%	1.1	2.8	0.1	5.0
	-20%	0.4	1.0	0.0	1.7
	-10%	0.2	0.5	0.0	0.8
	+10%	-0.2	-0.4	-0.8	0.0
	+20%	-0.4	-0.9	-1.5	0.0
	+50%	-0.9	-2.0	-3.4	-0.1
	+100%	-1.7	-3.5	-6.1	-0.1
Absolute changes in levies	+0.5 ct	-0.8	-0.7	-1.0	-0.4
	+1.0 ct	-1.5	-1.4	-2.0	-0.8
	+1.5 ct	-2.1	-2.1	-2.9	-1.2
Setting the effective levy	0.5ct	1.6	6.1	-0.7	12.1
	1ct	0.7	4.9	-1.4	10.6
	1.5ct	-0.1	3.7	-2.1	9.2
	2ct	-0.8	2.7	-2.9	8.0
Threshold for exemptions at 1ct/kWh	75% ex on full levy	0.0	-0.1	-0.4	0.3
	75% ex on amount above TH	-0.4	-0.5	-1.8	0.0
	85% ex on full levy	0.0	0.1	-0.2	0.5
	85% ex on amount above TH	-0.4	-0.4	-1.5	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.3	-0.1	-1.7	0.0
	75% ex on amount above TH	-0.5	-0.7	-2.4	0.0
	85% ex on full levy	-0.3	0.1	-1.7	0.3
	85% ex on amount above TH	-0.5	-0.6	-2.3	0.0
	75% ex on full levy	-0.3	-0.1	-1.7	0.0

Threshold for exemptions at 2ct/kWh	75% ex on amount above TH	-0.6	-0.9	-3.1	0.0
	85% ex on full levy	-0.3	0.1	-1.7	0.3
	85% ex on amount above TH	-0.6	-0.9	-3.0	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 69: Simulated average profitability changes (in %) for sanitary goods by country

Exp	AT	DE	DK	EL	FR	HR	LT	LV	PL	SI	SK
HI	-6.6	0.0	-8.2	-6.5	-9.0	-7.9	-7.8	-3.2	-8.3	-7.8	-4.8
No EX	0.0	0.0	-1.5	0.0	-3.7	-1.7	0.0	0.0	-0.2	0.0	0.0
-50%	1.3	5.0	0.4	0.6	0.6	0.1	1.0	1.1	0.3	0.4	1.0
-20%	0.5	1.7	0.2	0.2	0.2	0.0	0.4	0.4	0.1	0.2	0.4
-10%	0.2	0.8	0.1	0.1	0.1	0.0	0.2	0.2	0.1	0.1	0.2
+10%	-0.2	-0.8	-0.1	-0.1	-0.1	0.0	-0.2	-0.2	-0.1	-0.1	-0.2
+20%	-0.5	-1.5	-0.2	-0.2	-0.2	0.0	-0.4	-0.4	-0.1	-0.2	-0.4
+50%	-1.2	-3.4	-0.4	-0.6	-0.5	-0.1	-1.0	-1.0	-0.3	-0.4	-0.9
+100%	-2.2	-6.1	-0.8	-1.2	-1.0	-0.1	-1.9	-2.0	-0.6	-0.8	-1.7
+0.5 ct	-0.8	-0.6	-0.9	-0.7	-1.0	-0.8	-0.9	-0.4	-0.9	-0.8	-0.6
+1.0 ct	-1.5	-1.1	-1.7	-1.4	-2.0	-1.5	-1.7	-0.8	-1.7	-1.6	-1.1
+1.5 ct	-2.2	-1.6	-2.5	-2.0	-2.9	-2.2	-2.5	-1.2	-2.5	-2.3	-1.6
0.5ct (eff. l.)	1.7	12.1	-0.1	0.5	0.0	-0.7	1.1	1.8	-0.3	-0.1	1.4
1ct (eff. l.)	0.9	10.6	-1.0	-0.2	-1.0	-1.4	0.2	1.4	-1.2	-0.9	0.8
1.5ct (eff. l.)	0.1	9.2	-1.8	-0.9	-2.0	-2.1	-0.7	0.9	-2.0	-1.7	0.2
2ct (eff. l.)	-0.7	8.0	-2.6	-1.5	-2.9	-2.8	-1.5	0.5	-2.7	-2.4	-0.4
75% ex (1ct)	0.0	0.0	0.3	0.0	-0.3	-0.4	0.0	0.0	-0.2	0.0	0.0
75% ex cond. (1ct)	0.0	0.0	-1.1	0.0	-1.8	-1.5	0.0	0.0	-0.2	0.0	0.0
85% ex (1ct)	0.0	0.0	0.5	0.0	0.3	-0.2	0.0	0.0	-0.2	0.0	0.0
85% ex cond. (1ct)	0.0	0.0	-1.0	0.0	-1.5	-1.5	0.0	0.0	-0.2	0.0	0.0
75% ex (1.5ct)	0.0	0.0	-1.5	0.0	-0.3	-1.7	0.0	0.0	-0.2	0.0	0.0
75% ex cond. (1.5ct)	0.0	0.0	-1.5	0.0	-2.4	-1.7	0.0	0.0	-0.2	0.0	0.0

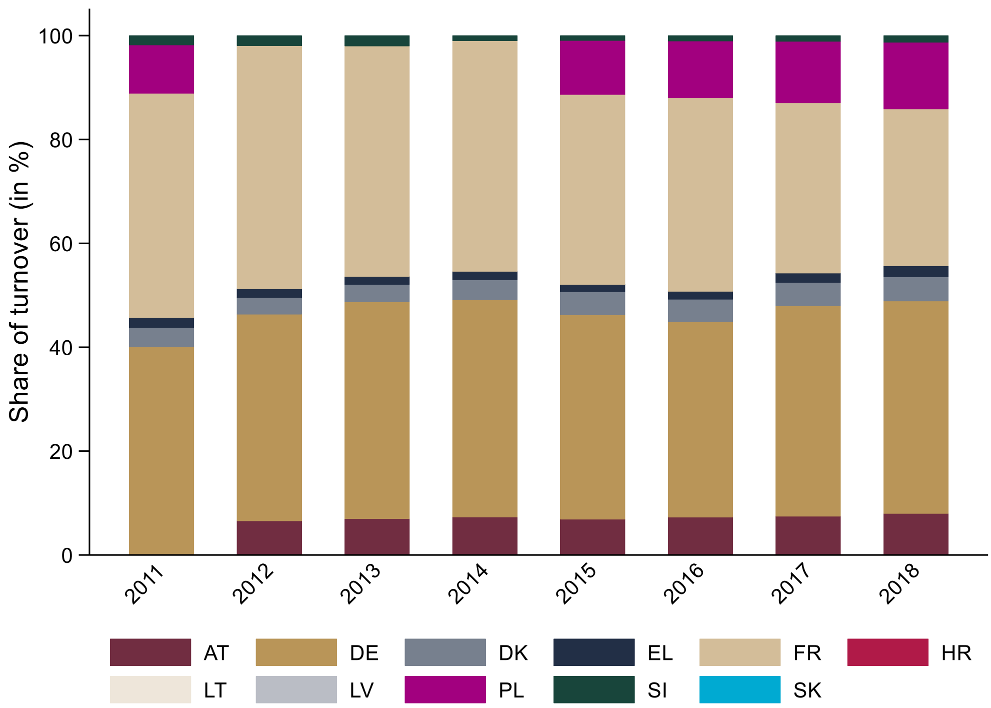
85% ex (1.5ct)	0.0	0.0	-1.5	0.0	0.3	-1.7	0.0	0.0	-0.2	0.0	0.0
85% ex cond. (1.5ct)	0.0	0.0	-1.5	0.0	-2.3	-1.7	0.0	0.0	-0.2	0.0	0.0
75% ex (2ct)	0.0	0.0	-1.5	0.0	-0.3	-1.7	0.0	0.0	-0.2	0.0	0.0
75% ex cond. (2ct)	0.0	0.0	-1.5	0.0	-3.1	-1.7	0.0	0.0	-0.2	0.0	0.0
85% ex (2ct)	0.0	0.0	-1.5	0.0	0.3	-1.7	0.0	0.0	-0.2	0.0	0.0
85% ex cond. (2ct)	0.0	0.0	-1.5	0.0	-3.0	-1.7	0.0	0.0	-0.2	0.0	0.0
Turnover (M. euro)	506	7287		602	4061	76	140		1585	149	327

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.5 Manufacture of industrial gases

"Manufacture of industrial gases" (NACE C20.11) is a sector located mainly in Germany and France and several small countries: Austria, Denmark, Greece, Poland and Slovenia, out of EU-11 countries. The following chart depicts the annual turnover shares by country. The turnover figure for France in 2018 was not available due to confidentiality reasons and we extrapolated it using the trend in the years 2015-2017.

Figure 87: Share of EU-11 turnover by country for manufacture of industrial gases



Source: Eurostat. Note: Turnover in France in 2018 extrapolated based on values form 2015-2017.

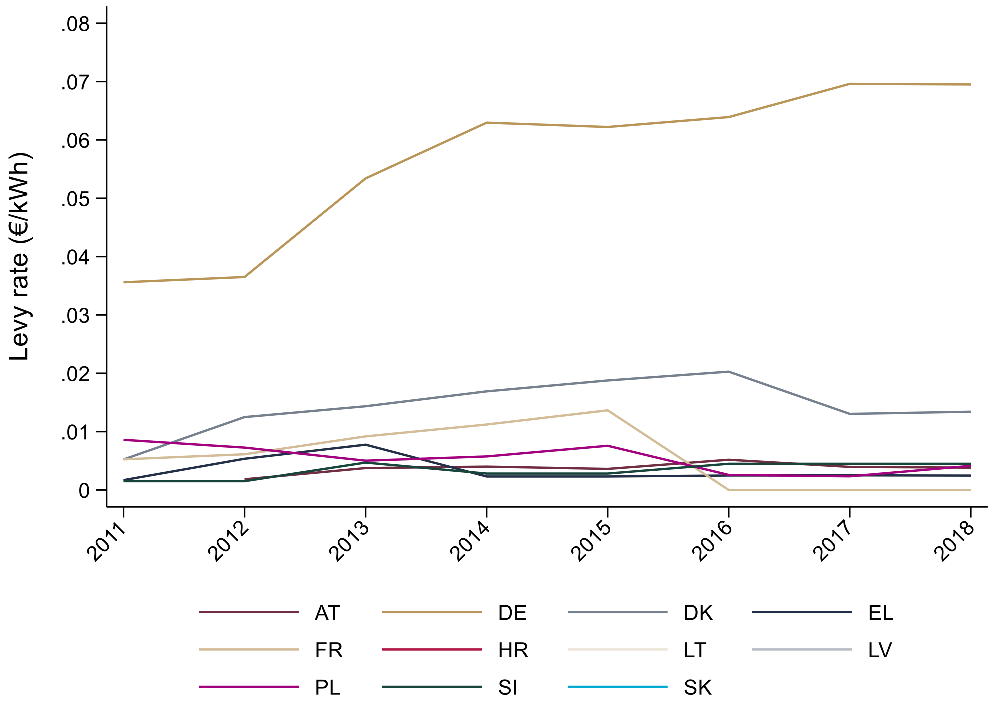
The sector is listed in Annex 3 of EEAG. Industrial gases nitrogen and oxygen are produced in air separation units and use a high amount of electricity.[359] The sector has the EU-11 average electro-intensity of 64.9%. A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Denmark, France, Germany, Poland and Slovenia. The degree of pass-on of cost increase indicated by the sector fiche was high[360] and we quantified it with 0.75. Six other sectors from the same NACE 3-digit sector C20.1 are all listed in Annex 3 of the EEAG:

- Manufacture of dyes and pigments (NACE C20.12);
- Manufacture of other inorganic basic chemicals (NACE C20.13);
- Manufacture of other organic basic chemicals (NACE C20.14);
- Manufacture of fertilisers and nitrogen compounds (NACE C20.15);
- Manufacture of plastics in primary forms (NACE C20.16);
- Manufacture of synthetic rubber in primary forms (NACE C20.17).

Annex 19.5.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of pulp were calculated over time before deducting the exemptions (levy without reductions) and after deducting the exemptions (effective levy). The following figures depict the time-development of both levy types per country.

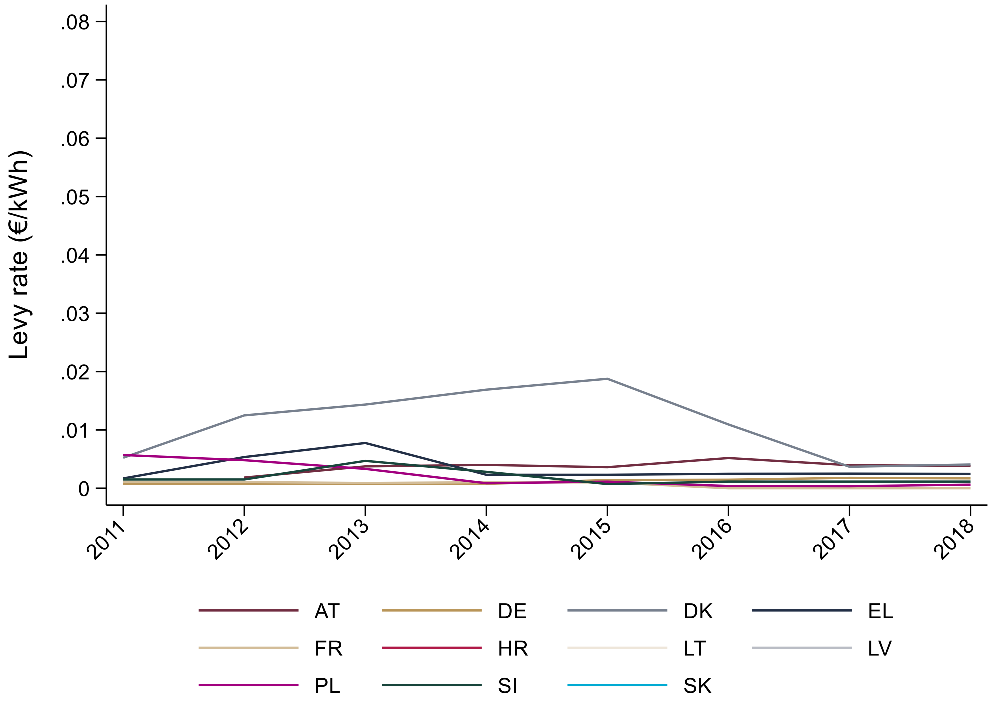
Figure 88: RES and CHP levies without reductions in manufacture of industrial gases



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

[359] "Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of industrial gases.
[360] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of industrial gases.

Figure 89: RES and CHP effective levies in manufacture of industrial gases

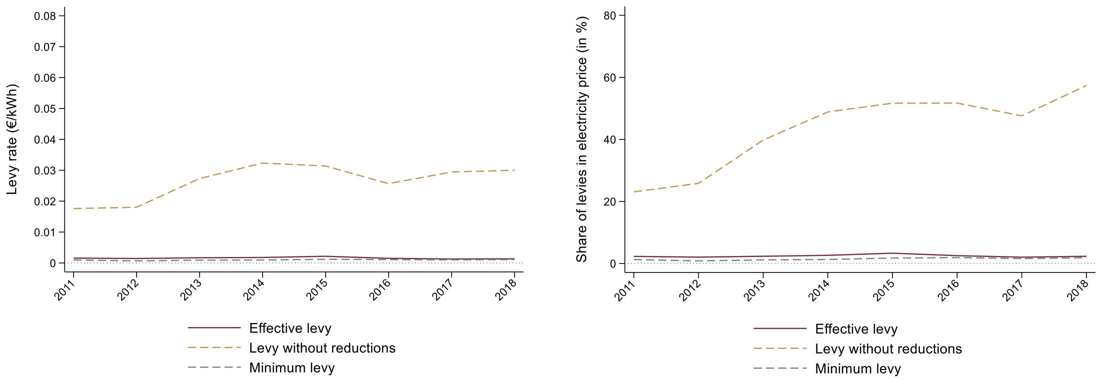


Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Comparing the levy for Germany in the above two figures, it is clear that the exemptions bring the levy in Germany to the level similar to other EU-11 countries. The highest levy without reductions is in Germany in every year, but the highest effective levy is in Denmark (2011-2016) and Germany (2017-2018). The lowest levies without exemptions are paid in Greece, Slovenia and Slovakia, for effective levies it is Germany, Poland, Slovenia and France.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 90: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of industrial gases

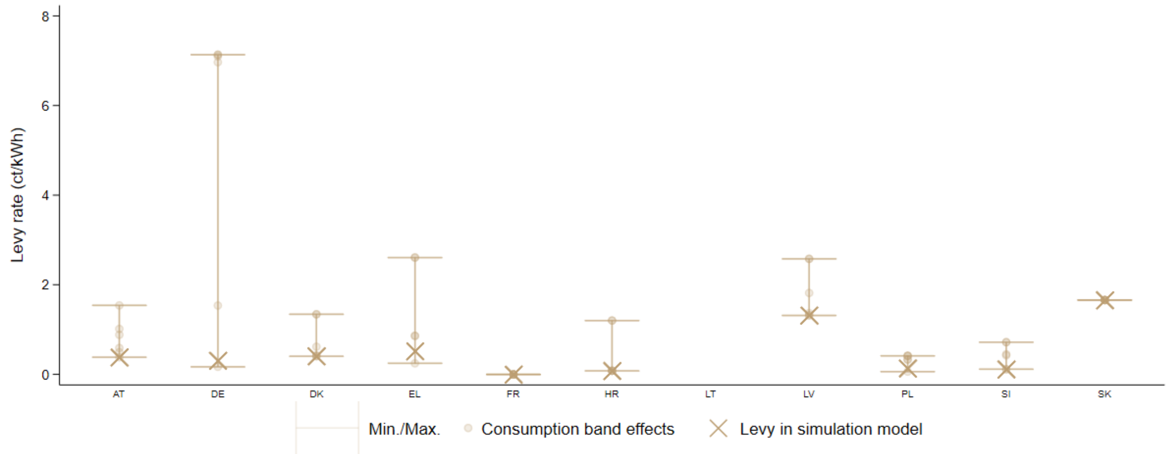


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 levies without reductions increase significantly from below 20% of electricity price in 2011 to about 40% in 2018. The exemptions reduce the paid levies to below 10% level. The effective levy increased in 2014 and again in 2018, which reflects the increase of effective levies in Germany (2014) and an increase in the share of turnover for Germany (2018). The small effective levy drop in the years 2016-2017 is driven by the low levy in France and Poland weighted with a large turnover share relative to other years.

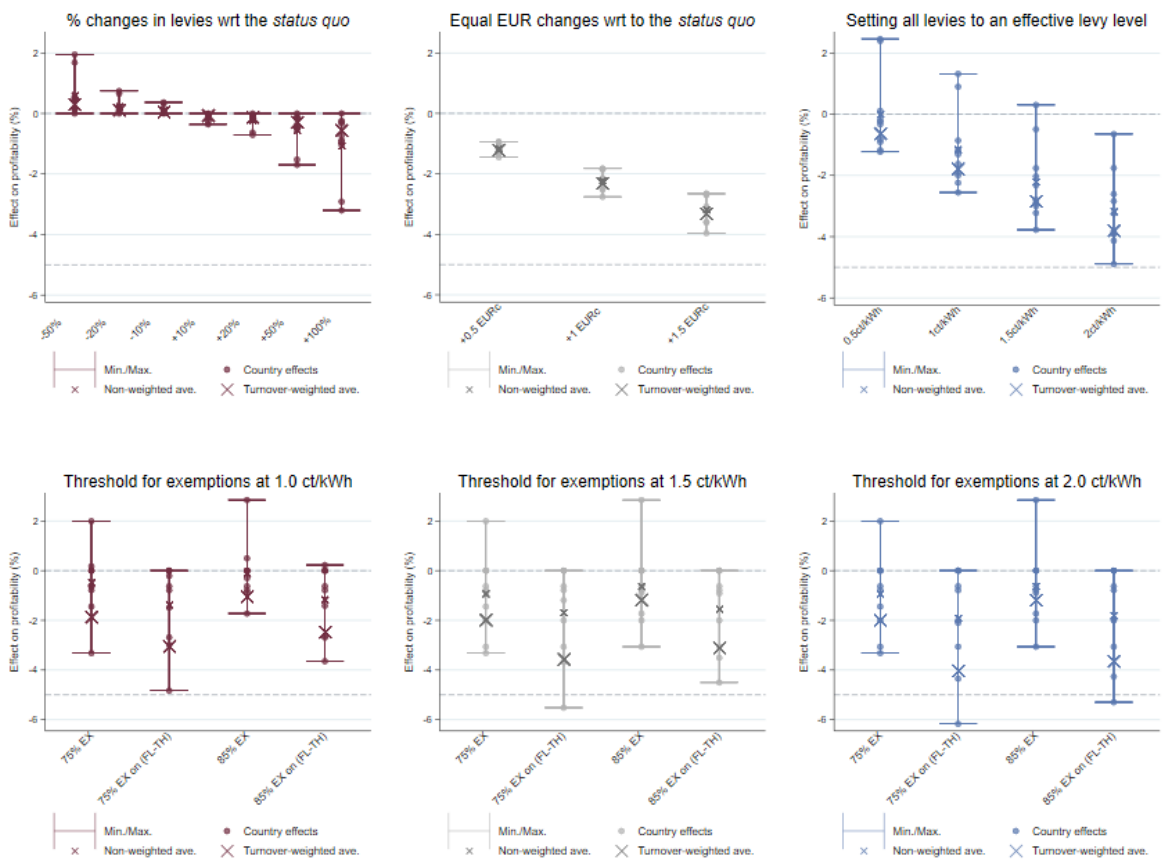
Annex 19.5.2 Detailed sectoral results from simulation model

Figure 91: Effective levy rate in 2018 per consumption band in industrial gases



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 92: Simulated profitability changes (%) per scenario for industrial gases



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 70: Simulated EU-11 average profitability changes (in %) for industrial gases

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-10.1	-10.6	-12.7	-7.9
	No exemptions	-2.6	-6.2	-11.2	0.0
% Changes to levies	-50%	0.6	0.3	0.0	1.9
	-20%	0.2	0.1	0.0	0.7
	-10%	0.1	0.1	0.0	0.4
	+10%	-0.1	-0.1	-0.4	0.0
	+20%	-0.2	-0.1	-0.7	0.0
	+50%	-0.5	-0.3	-1.7	0.0
	+100%	-1.1	-0.5	-3.2	0.0
Absolute changes in levies	+0.5 ct	-1.2	-1.2	-1.4	-0.9
	+1.0 ct	-2.2	-2.3	-2.8	-1.8
	+1.5 ct	-3.2	-3.3	-4.0	-2.7
Setting the effective levy	0.5ct	0.0	-0.6	-1.2	2.5
	1ct	-1.1	-1.8	-2.6	1.3
	1.5ct	-2.2	-2.8	-3.8	0.3
	2ct	-3.2	-3.8	-4.9	-0.6
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.5	-1.9	-3.3	2.0
	75% ex on amount above TH	-1.4	-3.0	-4.8	0.0
	85% ex on full levy	-0.1	-1.0	-1.7	2.8
	85% ex on amount above TH	-1.2	-2.5	-3.6	0.2
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.9	-2.0	-3.3	2.0
	75% ex on amount above TH	-1.7	-3.6	-5.5	0.0
	85% ex on full levy	-0.6	-1.2	-3.1	2.8
	85% ex on amount above TH	-1.5	-3.1	-4.5	0.0
	75% ex on full levy	-0.9	-2.0	-3.3	2.0

Threshold for exemptions at 2ct/kWh	75% ex on amount above TH	-1.9	-4.0	-6.2	0.0
	85% ex on full levy	-0.6	-1.2	-3.1	2.8
	85% ex on amount above TH	-1.8	-3.6	-5.3	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 71: Simulated average profitability changes (in %) for industrial gases by country

Exp	**AT**	**DE**	**DK**	**EL**	**FR**	**HR**	**LT**	**LV**	**PL**	**SI**	**SK**
HI	-8.8	-11.2	-9.9	-9.0	-10.6	-12.7		-10.2	-10.5	-10.5	-7.9
No EX	0.0	-11.2	-2.0	0.0	-5.0	-3.1		-3.1	-0.6	-0.8	0.0
-50%	0.4	0.5	0.5	0.6	0.0	0.1		1.9	0.2	0.1	1.7
-20%	0.2	0.2	0.2	0.2	0.0	0.0		0.7	0.1	0.1	0.7
-10%	0.1	0.1	0.1	0.1	0.0	0.0		0.4	0.0	0.0	0.3
+10%	-0.1	-0.1	-0.1	-0.1	0.0	0.0		-0.4	0.0	0.0	-0.3
+20%	-0.2	-0.2	-0.2	-0.2	0.0	0.0		-0.7	-0.1	-0.1	-0.6
+50%	-0.4	-0.5	-0.5	-0.5	0.0	-0.1		-1.7	-0.2	-0.1	-1.5
+100%	-0.7	-0.9	-0.9	-1.0	0.0	-0.2		-3.2	-0.3	-0.3	-2.9
+0.5 ct	-1.0	-1.3	-1.1	-1.0	-1.2	-1.4		-1.3	-1.1	-1.2	-0.9
+1.0 ct	-1.8	-2.5	-2.1	-1.9	-2.2	-2.8		-2.5	-2.2	-2.2	-1.8
+1.5 ct	-2.7	-3.6	-3.1	-2.7	-3.2	-4.0		-3.6	-3.2	-3.2	-2.7
0.5ct (eff. l.)	-0.2	-0.3	-0.2	0.1	-1.2	-1.2		2.5	-0.8	-0.9	2.4
1ct (eff. l.)	-1.2	-1.6	-1.3	-0.9	-2.2	-2.6		0.9	-1.9	-2.0	1.3
1.5ct (eff. l.)	-2.0	-2.8	-2.3	-1.8	-3.2	-3.8		-0.5	-2.9	-3.0	0.3
2ct (eff. l.)	-2.8	-3.9	-3.2	-2.6	-4.1	-4.9		-1.8	-3.8	-3.9	-0.6
75% ex (1ct)	0.0	-3.3	0.2	0.0	-1.4	-0.7		2.0	-0.6	-0.8	0.0
75% ex cond. (1ct)	0.0	-4.8	-1.5	0.0	-3.0	-2.7		-0.2	-0.6	-0.8	0.0
85% ex (1ct)	0.0	-1.7	0.5	0.0	-0.9	-0.3		2.8	-0.6	-0.8	0.0
85% ex cond. (1ct)	0.0	-3.6	-1.4	0.0	-2.7	-2.6		0.2	-0.6	-0.8	0.0
75% ex (1.5ct)	0.0	-3.3	-2.0	0.0	-1.4	-3.1		2.0	-0.6	-0.8	0.0
75% ex cond. (1.5ct)	0.0	-5.5	-2.0	0.0	-3.7	-3.1		-1.2	-0.6	-0.8	0.0

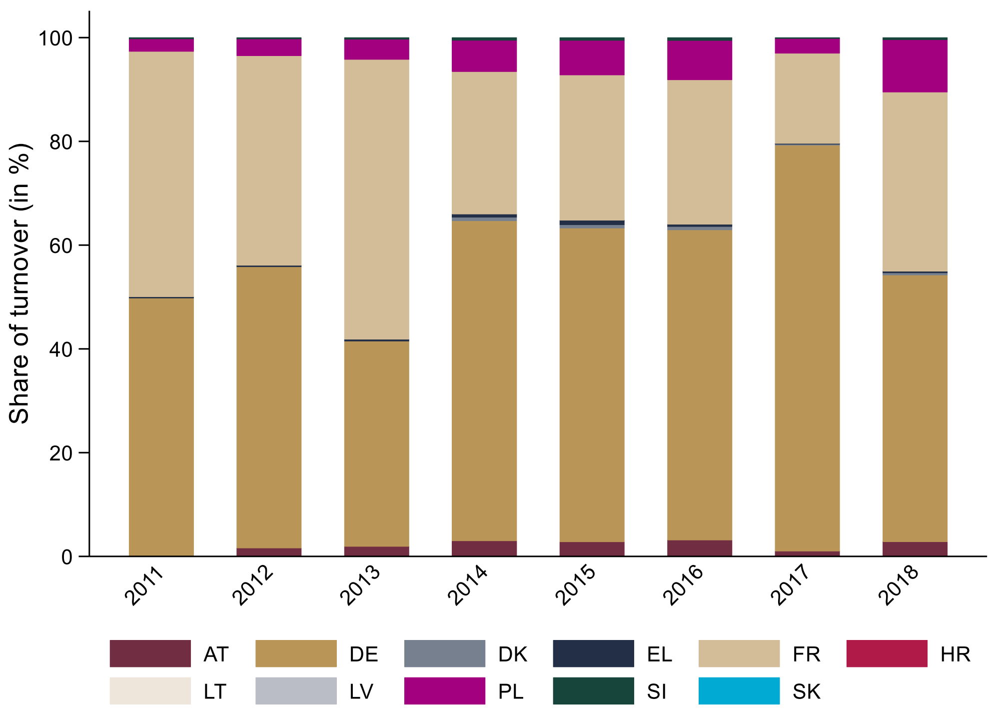
85% ex (1.5ct)	0.0	-1.7	-2.0	0.0	-0.9	-3.1		2.8	-0.6	-0.8	0.0
85% ex cond. (1.5ct)	0.0	-4.5	-2.0	0.0	-3.5	-3.1		-0.9	-0.6	-0.8	0.0
75% ex (2ct)	0.0	-3.3	-2.0	0.0	-1.4	-3.1		2.0	-0.6	-0.8	0.0
75% ex cond. (2ct)	0.0	-6.2	-2.0	0.0	-4.3	-3.1		-2.1	-0.6	-0.8	0.0
85% ex (2ct)	0.0	-1.7	-2.0	0.0	-0.9	-3.1		2.8	-0.6	-0.8	0.0
85% ex cond. (2ct)	0.0	-5.3	-2.0	0.0	-4.3	-3.1		-2.0	-0.6	-0.8	0.0
Turnover (M. euro)	336	1771	200	85	1370	45			538	52	33

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.6 Manufacture of other inorganic basic chemicals

"Manufacture of other inorganic basic chemicals" (NACE 20.13) is a sector located mainly in Germany and France, with minor turnover share coming from Austria, Denmark, Greece, Poland and Slovenia, out of the EU-11 countries. The following chart depicts annual turnover shares by country.

Figure 93: Share of EU-11 turnover by country for manufacture of other inorganic basic chemicals



Source: Eurostat.

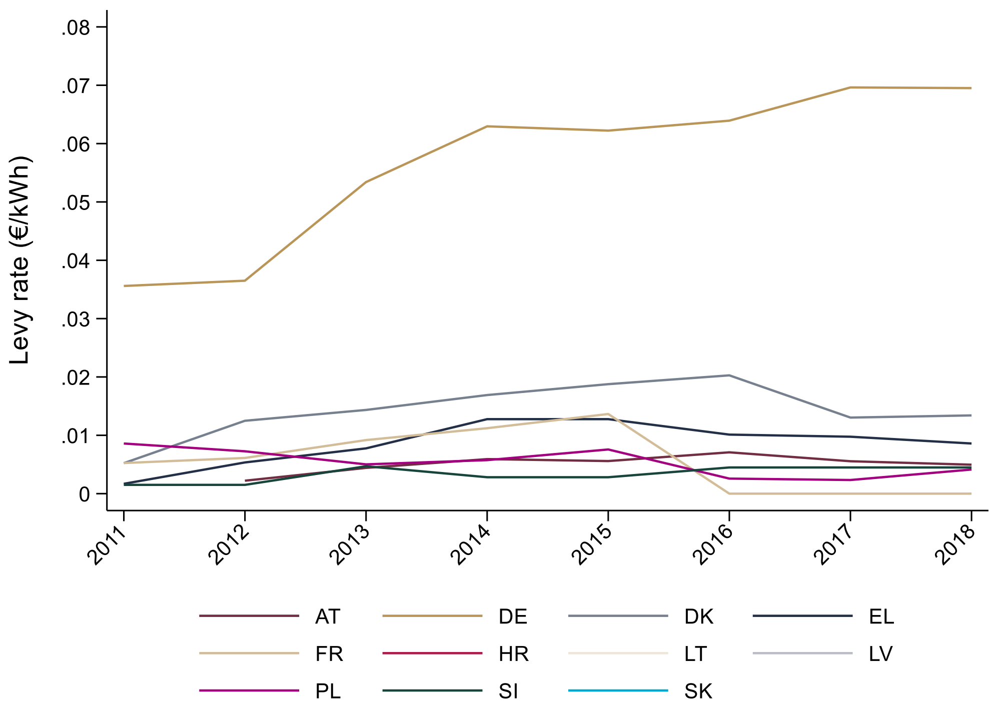
The sector is listed in Annex 3 of the EEAG. It has the average electro-intensity of 34.67%. There were no studies available, which would allow to assess the plausibility of this figure. The sector. A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Denmark, France, Germany, Poland and Slovenia. The degree of pass-on of cost increase indicated by the sector fiche was low[361] and we quantified it with 0.25. Six other sectors from the same NACE 3-digit sector C20.1 are all listed in Annex 3 of the EEAG:

- Manufacture of industrial gases (NACE C20.11);
- Manufacture of dyes and pigments (NACE C20.12);
- Manufacture of other organic basic chemicals (NACE C20.14);
- Manufacture of fertilisers and nitrogen compounds (NACE C20.15);
- Manufacture of plastics in primary forms (NACE C20.16);
- Manufacture of synthetic rubber in primary forms (NACE C20.17).

Annex 19.6.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of other inorganic basic chemicals were calculated over time for both Non-EIUs (before deducting the exemptions) and EIUs (after deducting the exemptions). The following figures depict the time-development of both levies per country.

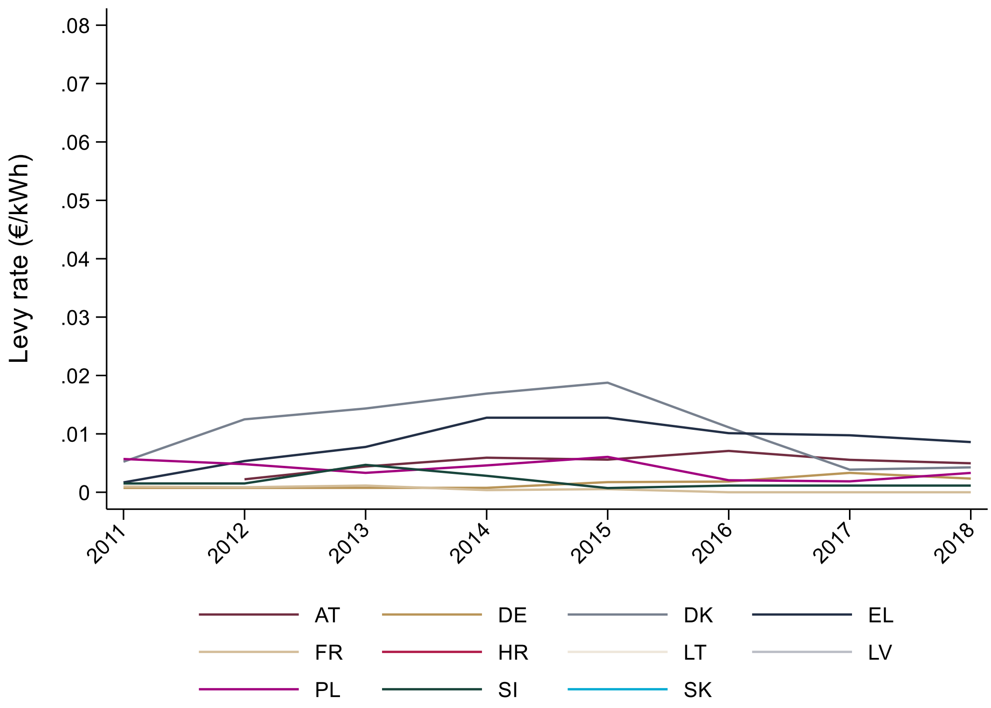
Figure 94: RES and CHP levies without reductions in manufacture of other inorganic basic chemicals



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

361 Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of other inorganic basic chemicals.

Figure 95: RES and CHP effective levies in manufacture of other inorganic basic chemicals

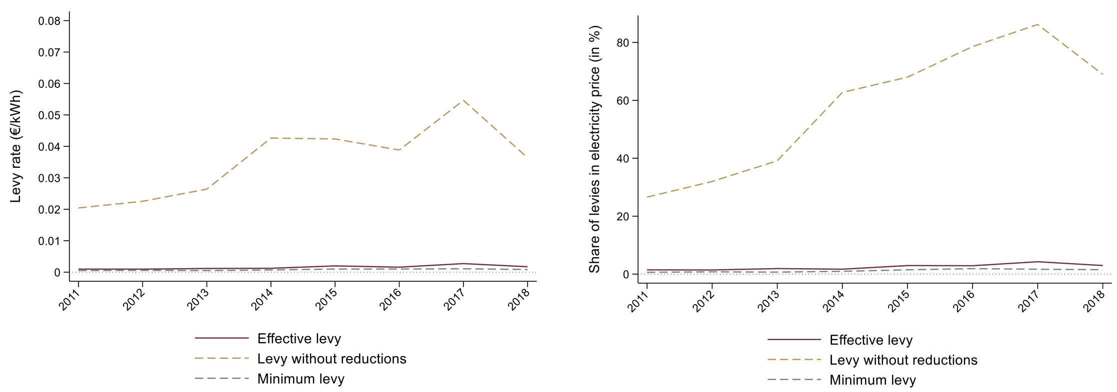


Source: Support study. European Commission, Eurostat, and own calculations.

Comparing the levy for Germany in the above two figures, it is clear that the exemptions bring the levy in Germany to the level similar to other EU-11 countries. The highest levy without reductions is in Germany in every year, but the highest effective levy is in Denmark (2011-2016) and Germany (2017-2018). The lowest levies without exemptions are paid in Slovenia and France, for effective levies it is Germany, France and Slovenia.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 96: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of other inorganic basic chemicals

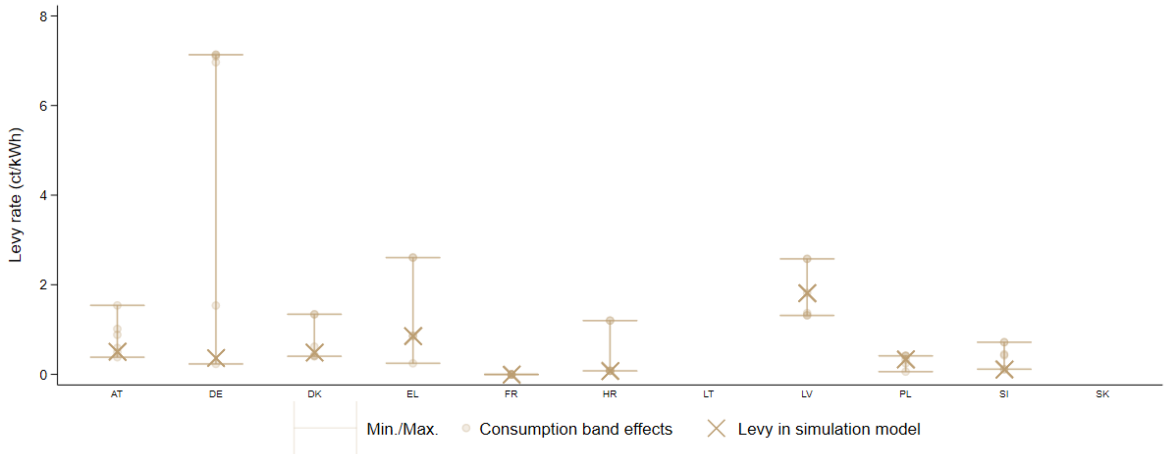


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 levies without reductions increase significantly from about 20% of electricity price in 2011 to almost 60% in 2017 and drop a bit in 2018. This reflects the development of Germany's share in the EU-11 turnover. The exemptions reduce the paid levies very strongly to below 10% level. The effective levy increased over time with a shift in 2014, which reflects the increase of effective levies in Germany.

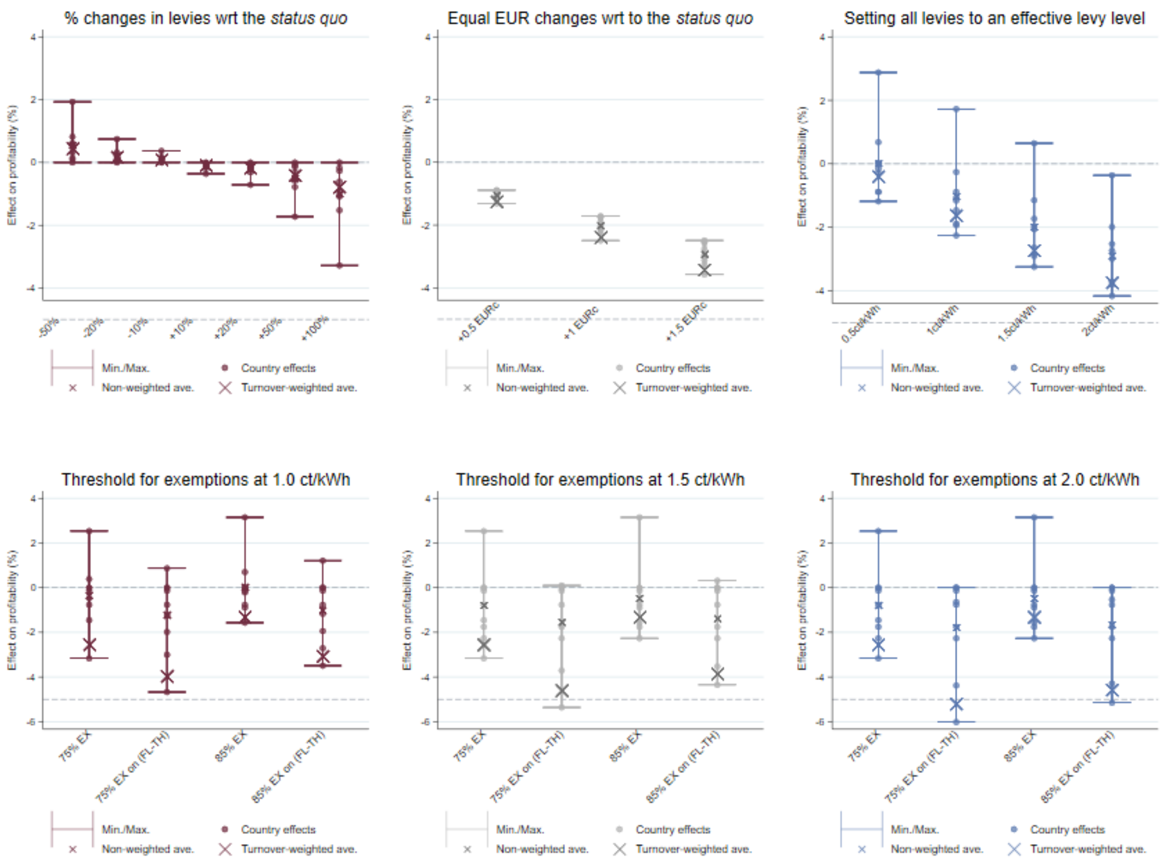
Annex 19.6.2 Detailed sectoral results from simulation model

Figure 97: Effective levy rate in 2018 per consumption band in inorganic chemicals



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 98: Simulated profitability changes (%) per scenario for inorganic chemicals



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 72: Simulated EU-11 average profitability changes (in %) for inorganic chemicals

	Experiment	**Average non-weighted**	**Average turnover-weighted**	**Minimum effect across countries**	**Maximum effect across countries**
Unexempted levy or highest levy	Highest sector-specific levy	-9.5	-10.8	-11.0	-7.9
	No exemptions	-2.5	-8.8	-11.0	0.0
% Changes to levies	-50%	0.6	0.4	0.0	1.9
	-20%	0.2	0.2	0.0	0.7
	-10%	0.1	0.1	0.0	0.4
	+10%	-0.1	-0.1	-0.4	0.0
	+20%	-0.2	-0.2	-0.7	0.0
	+50%	-0.5	-0.4	-1.7	0.0
	+100%	-1.0	-0.8	-3.3	0.0
Absolute changes in levies	+0.5 ct	-1.0	-1.2	-1.3	-0.9
	+1.0 ct	-2.0	-2.4	-2.5	-1.7
	+1.5 ct	-2.9	-3.4	-3.6	-2.5
Setting the effective levy	0.5ct	0.0	-0.4	-1.2	2.9
	1ct	-1.0	-1.6	-2.3	1.7
	1.5ct	-2.0	-2.7	-3.2	0.6
	2ct	-2.9	-3.7	-4.2	-0.4
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.3	-2.5	-3.2	2.5
	75% ex on amount above TH	-1.2	-4.0	-4.7	0.9
	85% ex on full levy	0.0	-1.3	-1.6	3.1
	85% ex on amount above TH	-1.0	-3.1	-3.5	1.2
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.8	-2.5	-3.2	2.5
	75% ex on amount above TH	-1.5	-4.6	-5.4	0.1
	85% ex on full levy	-0.5	-1.3	-2.3	3.1
	85% ex on amount above TH	-1.4	-3.8	-4.3	0.3
	75% ex on full levy	-0.8	-2.5	-3.2	2.5

Threshold for exemptions at 2ct/kWh	75% ex on amount above TH	-1.8	-5.2	-6.0	0.0
	85% ex on full levy	-0.5	-1.3	-2.3	3.1
	85% ex on amount above TH	-1.7	-4.6	-5.1	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 73: Simulated average profitability changes (in %) for for inorganic chemicals by country

Exp	AT	DE	DK	EL	FR	HR	LT	LV	PL	SI	SK
HI	-8.4	-11.0	-9.7	-8.5	-10.7	-10.5		-7.9	-8.4	-10.2	
No EX	0.0	-11.0	-1.8	0.0	-5.0	-2.3		-1.5	-0.1	-0.8	
-50%	0.5	0.6	0.6	0.8	0.0	0.1		1.9	0.3	0.1	
-20%	0.2	0.2	0.2	0.3	0.0	0.0		0.7	0.1	0.1	
-10%	0.1	0.1	0.1	0.2	0.0	0.0		0.4	0.1	0.0	
+10%	-0.1	-0.1	-0.1	-0.2	0.0	0.0		-0.4	-0.1	0.0	
+20%	-0.2	-0.2	-0.2	-0.3	0.0	0.0		-0.7	-0.1	-0.1	
+50%	-0.5	-0.5	-0.6	-0.8	0.0	-0.1		-1.7	-0.3	-0.1	
+100%	-0.9	-1.0	-1.1	-1.5	0.0	-0.2		-3.3	-0.6	-0.3	
+0.5 ct	-0.9	-1.3	-1.1	-0.9	-1.2	-1.1		-1.0	-0.9	-1.1	
+1.0 ct	-1.7	-2.5	-2.1	-1.8	-2.3	-2.0		-1.9	-1.7	-2.2	
+1.5 ct	-2.5	-3.6	-3.0	-2.6	-3.2	-3.0		-2.8	-2.5	-3.1	
0.5ct (eff. l.)	0.0	-0.2	0.0	0.7	-1.2	-0.9		2.9	-0.3	-0.9	
1ct (eff. l.)	-0.9	-1.5	-1.1	-0.3	-2.3	-1.9		1.7	-1.2	-1.9	
1.5ct (eff. l.)	-1.7	-2.6	-2.1	-1.1	-3.2	-2.8		0.6	-2.0	-2.9	
2ct (eff. l.)	-2.5	-3.7	-3.0	-2.0	-4.2	-3.7		-0.4	-2.7	-3.8	
75% ex (1ct)	0.0	-3.2	0.4	0.0	-1.5	-0.5		2.5	-0.1	-0.8	
75% ex cond. (1ct)	0.0	-4.7	-1.2	0.0	-3.0	-2.0		0.9	-0.1	-0.8	
85% ex (1ct)	0.0	-1.6	0.7	0.0	-0.9	-0.2		3.1	-0.1	-0.8	
85% ex cond. (1ct)	0.0	-3.5	-1.2	0.0	-2.7	-1.9		1.2	-0.1	-0.8	
75% ex (1.5ct)	0.0	-3.2	-1.8	0.0	-1.5	-2.3		2.5	-0.1	-0.8	
75% ex cond. (1.5ct)	0.0	-5.4	-1.8	0.0	-3.7	-2.3		0.1	-0.1	-0.8	

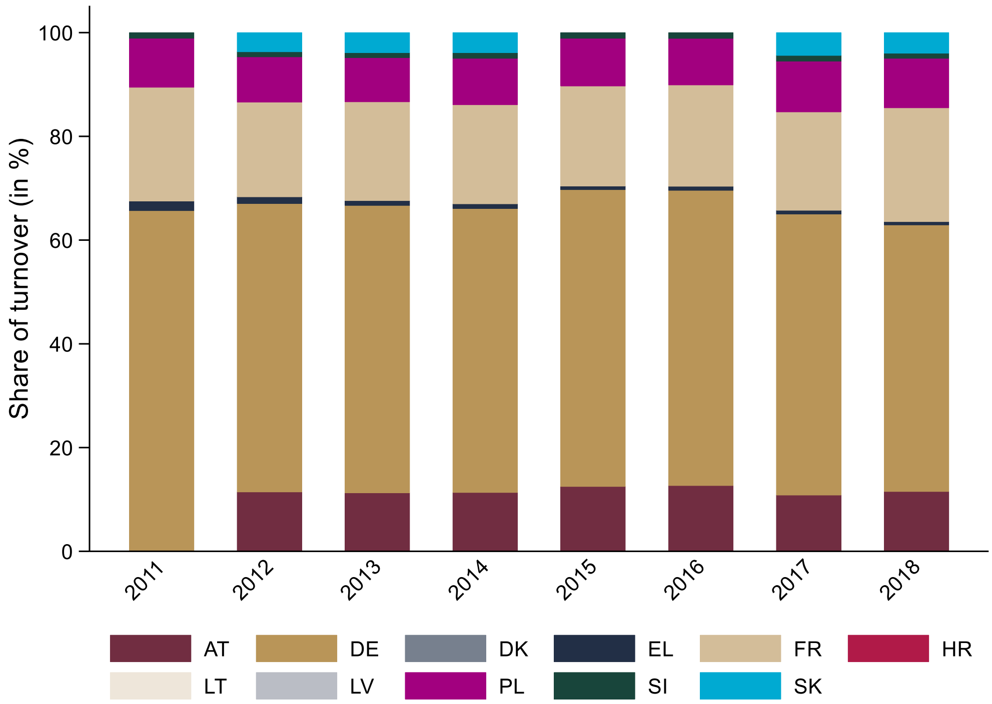
85% ex (1.5ct)	0.0	-1.6	-1.8	0.0	-0.9	-2.3		3.1	-0.1	-0.8
85% ex cond. (1.5ct)	0.0	-4.3	-1.8	0.0	-3.5	-2.3		0.3	-0.1	-0.8
75% ex (2ct)	0.0	-3.2	-1.8	0.0	-1.5	-2.3		2.5	-0.1	-0.8
75% ex cond. (2ct)	0.0	-6.0	-1.8	0.0	-4.4	-2.3		-0.6	-0.1	-0.8
85% ex (2ct)	0.0	-1.6	-1.8	0.0	-0.9	-2.3		3.1	-0.1	-0.8
85% ex cond. (2ct)	0.0	-5.1	-1.8	0.0	-4.3	-2.3		-0.5	-0.1	-0.8
Turnover (M. euro)	330	14260	54	41	4701	4		1	1061	51

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.7 Manufacture of basic iron and steel and of ferro-alloys

"Manufacture of basic iron and steel and of ferro-alloys" (NACE C24.10) is a sector located mainly in Germany and France, with smaller shares form Austria, Greece, Poland, Slovenia and Slovakia, out of the EU-11. The following chart depicts annual turnover shares by country.

Figure 99: Share of EU-11 turnover by country for manufacture of basic iron and steel and of ferro-alloys



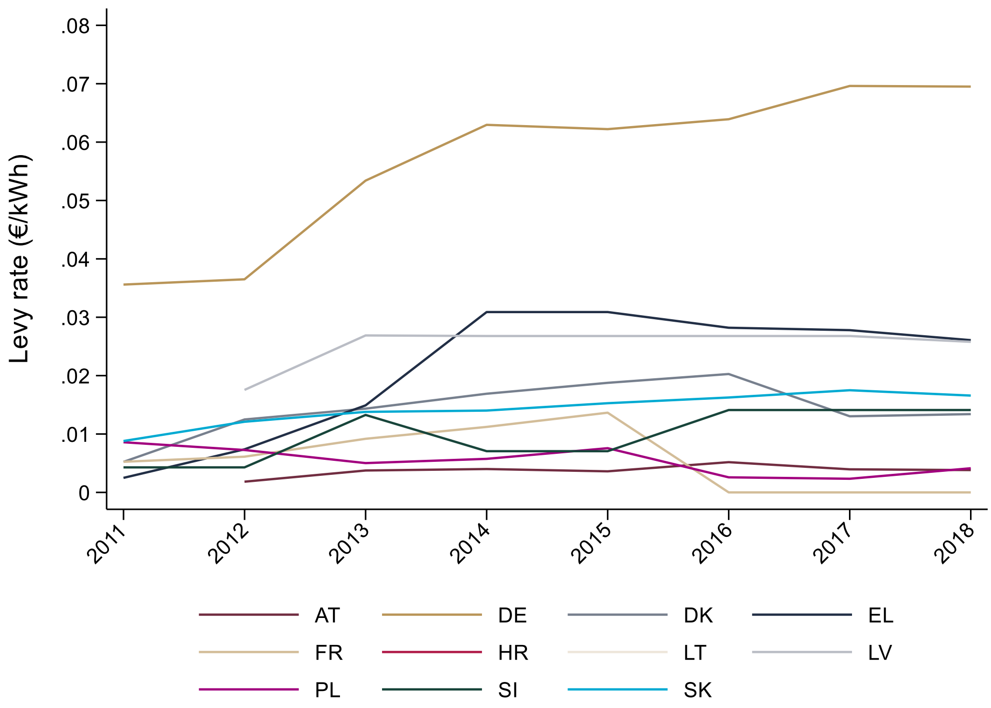
Source: Eurostat.

The sector is listed in Annex 3 of EEAG. In the primary steel manufacturing, electricity provides only 7% of energy required in the production process. In the secondary steel production by melting scrap, electricity provides 50% of required energy.[362] The report by Grave et al. (2015) assumes 12% share of electricity cost in the gross value added for a primary manufacturing plant and 22% for a fully electric plant.[363] Electro-intensity of the steel sector in our data is higher: the EU-11 average electro-intensity hits 32.21%. A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Denmark, France, Germany, Poland and Slovenia. The degree of pass-on of cost increase indicated by the sector fiche[364] was medium and we quantified it with 0.5. It is the only NACE 4-digit sector in the NACE 3-digit sector C24.1.

Annex 19.7.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in the manufacture of basic iron and steel and of ferro-alloys were calculated over time before deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levy types per country.

Figure 100: RES and CHP levies without reductions in manufacture of basic iron and steel and of ferro-alloys



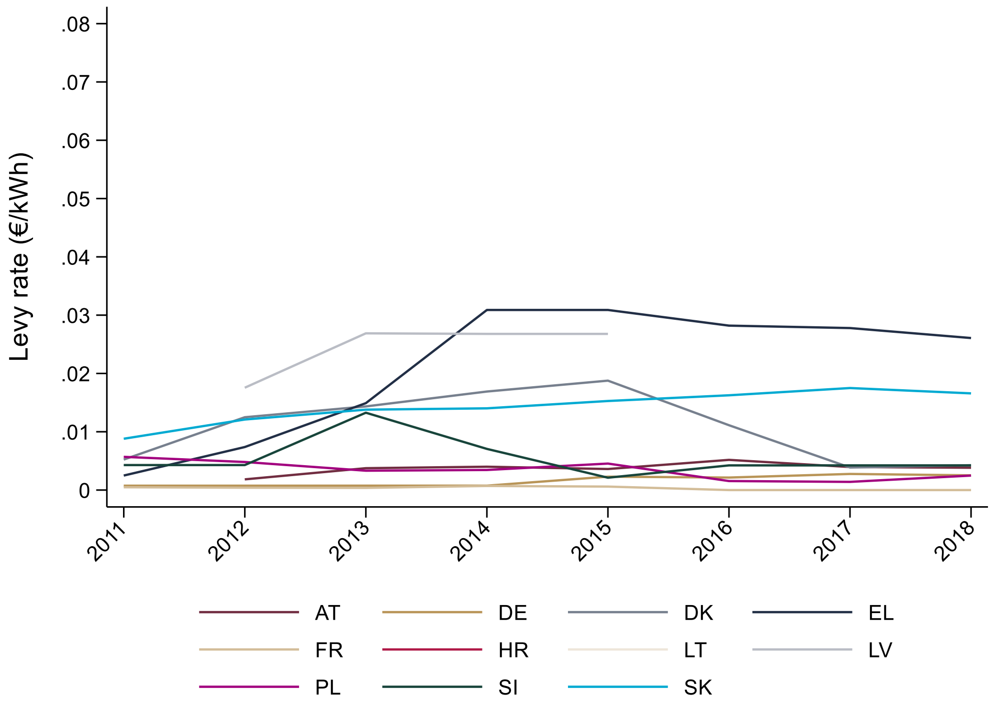
Source: Support study. European Commission, Eurostat, and own calculations.

[362] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of basic iron and steel and of ferro-alloys.

[363] Grave K., M. Hazrat, S. Boeve, F. von Blücher, CH. Bourgault, B. Breitschopf, N. Friedrichsen, M. Arens, A. Aydemir, M. Pudlik, V. Duscha, J. Ordonez, G. Lutz, A. Großmann, M. Flaute, "Electricity Costs of Energy Intensive Industries. An international Comparison." July 2015, page 43.

[364] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Manufacture of basic iron and steel and of ferro-alloys.

Figure 101: RES and CHP effective levies in manufacture of basic iron and steel and of ferro-alloys

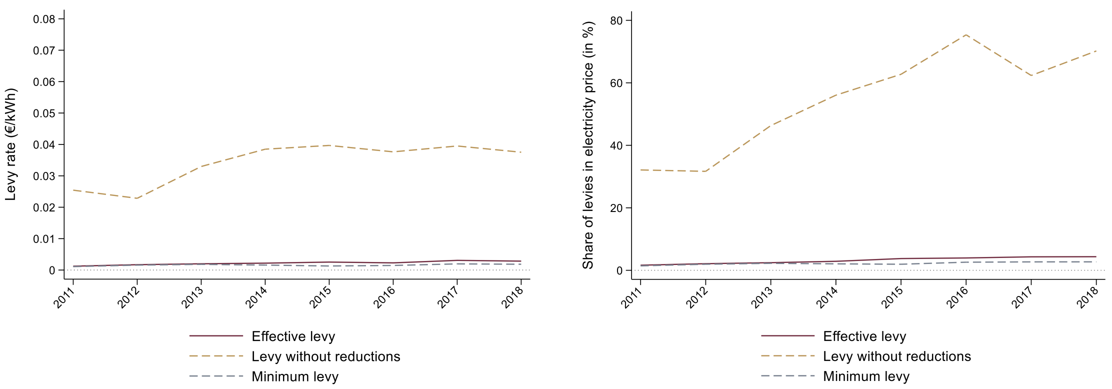


Source: Support study. European Commission, Eurostat, and own calculations.

Comparing the levy for Germany in the above two figures, it is clear that the exemptions bring the levy in Germany to the level similar to other EU-11 countries. The highest levy without reductions is in Germany in every year, but the highest effective levy is in Slovakia (2011), Denmark (2011-2012) and Greece (2014-2018). The lowest levies without exemptions are paid in Greece (2011), Austria (2012-2015) and France (as of 2016), for effective levies it is Germany (until 2013) and France (as of 2014), matched by Slovenia in 2015.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 102: EU-11 average RES and CHP levy and its share in the electricity bill in the manufacture of basic iron and steel and of ferro-alloys

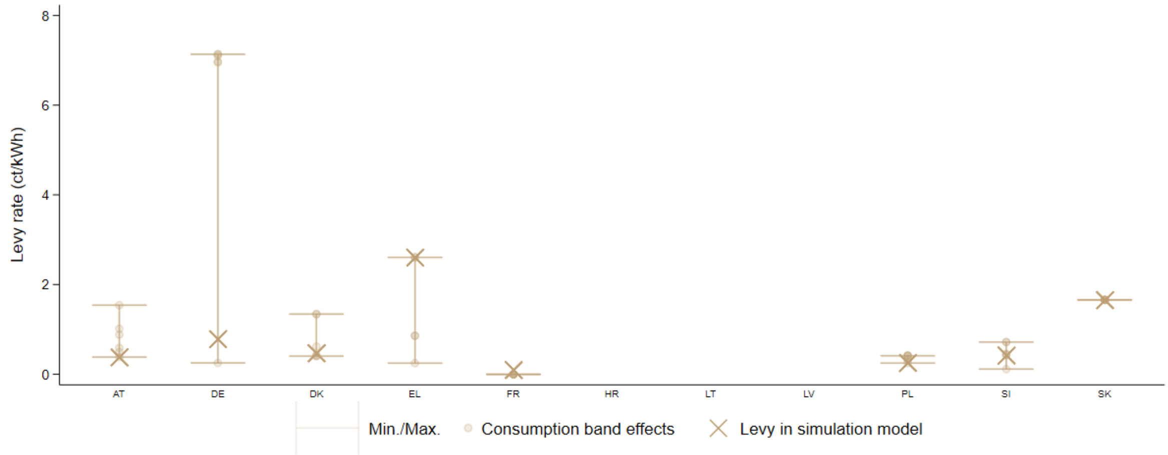


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 levies without reductions increase from about 25% of electricity price in 2011 to about 45% in 2018. The exemptions reduce the paid levies very strongly to below 10% level. The effective levy is flat over time with a shift in 2014, which reflects the increase of effective levies in Germany and in Greece.

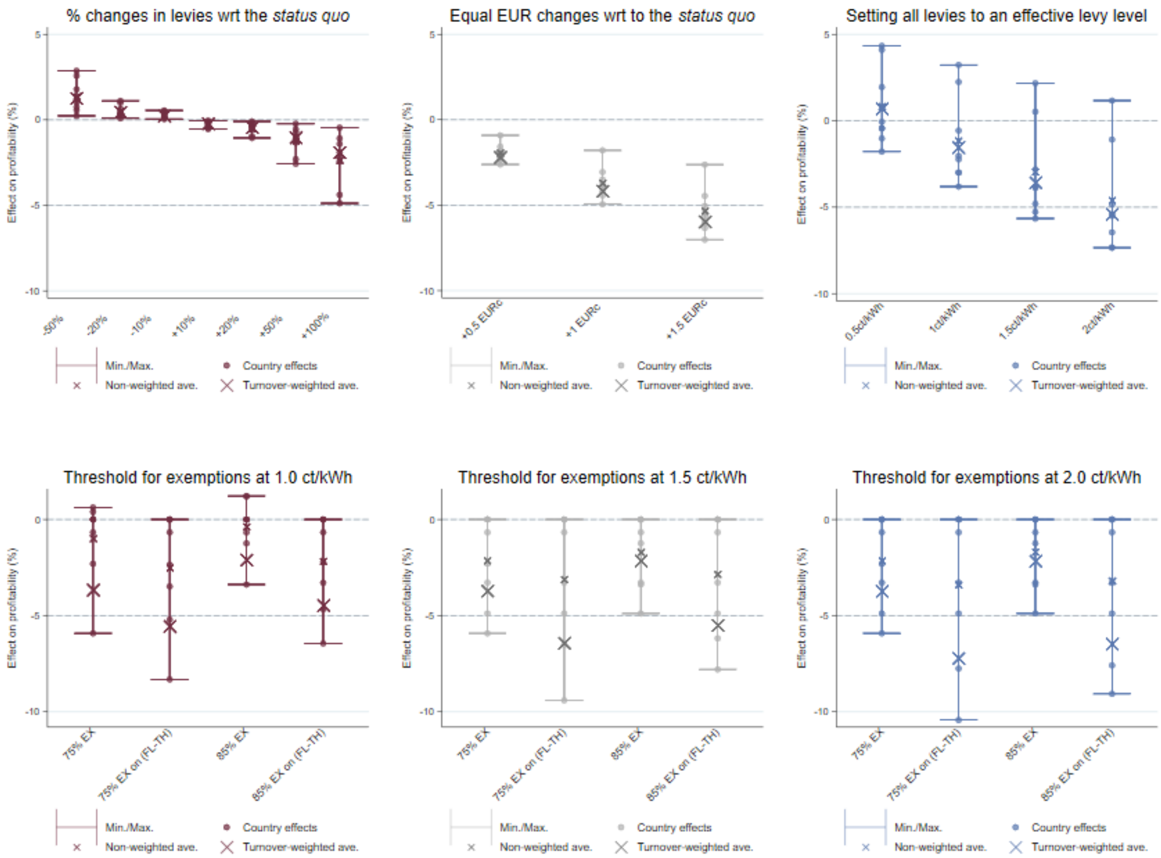
Annex 19.7.2 Detailed sectoral results from simulation model

Figure 103: Effective levy rate in 2018 per consumption band in iron and steel



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 104: Simulated profitability changes (%) per scenario for iron and steel



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 74: Simulated EU-11 average profitability changes (in %) for basic iron and steel of ferro-alloys

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-16.1	-17.8	-20.5	-6.9
	No exemptions	-4.5	-11.5	-18.2	0.0
% Changes to levies	-50%	1.4	1.3	0.2	2.9
	-20%	0.5	0.5	0.1	1.1
	-10%	0.3	0.2	0.0	0.5
	+10%	-0.3	-0.2	-0.5	0.0
	+20%	-0.5	-0.4	-1.1	-0.1
	+50%	-1.2	-1.0	-2.6	-0.2
	+100%	-2.4	-1.9	-4.9	-0.5
Absolute changes in levies	+0.5 ct	-1.9	-2.2	-2.6	-0.9
	+1.0 ct	-3.7	-4.2	-4.9	-1.8
	+1.5 ct	-5.3	-6.0	-7.0	-2.6
Setting the effective levy	0.5ct	0.8	0.7	-1.8	4.3
	1ct	-1.1	-1.5	-3.8	3.2
	1.5ct	-2.9	-3.6	-5.7	2.2
	2ct	-4.6	-5.4	-7.3	1.2
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-1.0	-3.7	-5.9	0.6
	75% ex on amount above TH	-2.5	-5.6	-8.3	0.0
	85% ex on full levy	-0.4	-2.1	-3.4	1.2
	85% ex on amount above TH	-2.2	-4.5	-6.4	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-2.1	-3.7	-5.9	0.0
	75% ex on amount above TH	-3.1	-6.4	-9.4	0.0
	85% ex on full levy	-1.7	-2.2	-4.9	0.0
	85% ex on amount above TH	-2.9	-5.5	-7.8	0.0
	75% ex on full levy	-2.1	-3.7	-5.9	0.0

Threshold for exemptions at 2ct/kWh	75% ex on amount above TH	-3.4	-7.2	-10.4	0.0
	85% ex on full levy	-1.7	-2.2	-4.9	0.0
	85% ex on amount above TH	-3.2	-6.4	-9.1	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 75: Simulated average profitability changes (in %) for basic iron and steel of ferro-alloys by country

Exp	AT	DE	DK	EL	FR	HR	LT	LV	PL	SI	SK
HI	-16.2	-18.2	-17.2	-6.9	-18.9				-18.0	-20.5	-12.9
No EX	0.0	-18.2	-3.3	0.0	-8.9				-0.7	-4.9	0.0
-50%	0.7	1.8	1.0	2.6	0.2				0.6	1.2	2.9
-20%	0.3	0.6	0.4	1.0	0.1				0.2	0.5	1.1
-10%	0.1	0.3	0.2	0.5	0.0				0.1	0.2	0.5
+10%	-0.1	-0.3	-0.2	-0.5	0.0				-0.1	-0.2	-0.5
+20%	-0.3	-0.6	-0.4	-1.0	-0.1				-0.2	-0.5	-1.1
+50%	-0.7	-1.3	-1.0	-2.3	-0.2				-0.6	-1.1	-2.6
+100%	-1.4	-2.4	-1.9	-4.4	-0.5				-1.1	-2.2	-4.9
+0.5 ct	-1.8	-2.3	-2.0	-0.9	-2.2				-2.1	-2.6	-1.6
+1.0 ct	-3.5	-4.4	-3.8	-1.8	-4.2				-3.9	-4.9	-3.1
+1.5 ct	-5.0	-6.3	-5.5	-2.6	-6.0				-5.7	-7.0	-4.5
0.5ct (eff. l.)	-0.4	1.9	-0.1	4.3	-1.8				-1.0	-0.4	4.1
1ct (eff. l.)	-2.2	-0.6	-2.0	3.2	-3.8				-3.0	-3.0	2.2
1.5ct (eff. l.)	-3.9	-2.8	-3.8	2.2	-5.7				-4.8	-5.3	0.5
2ct (eff. l.)	-5.4	-4.8	-5.5	1.2	-7.3				-6.5	-7.3	-1.1
75% ex (1ct)	0.0	-5.9	0.6	0.0	-2.3				-0.7	0.4	0.0
75% ex cond. (1ct)	0.0	-8.3	-2.4	0.0	-5.2				-0.7	-3.5	0.0
85% ex (1ct)	0.0	-3.4	1.2	0.0	-1.2				-0.7	1.2	0.0
85% ex cond. (1ct)	0.0	-6.4	-2.2	0.0	-4.7				-0.7	-3.3	0.0
75% ex (1.5ct)	0.0	-5.9	-3.3	0.0	-2.3				-0.7	-4.9	0.0
75% ex cond. (1.5ct)	0.0	-9.4	-3.3	0.0	-6.5				-0.7	-4.9	0.0

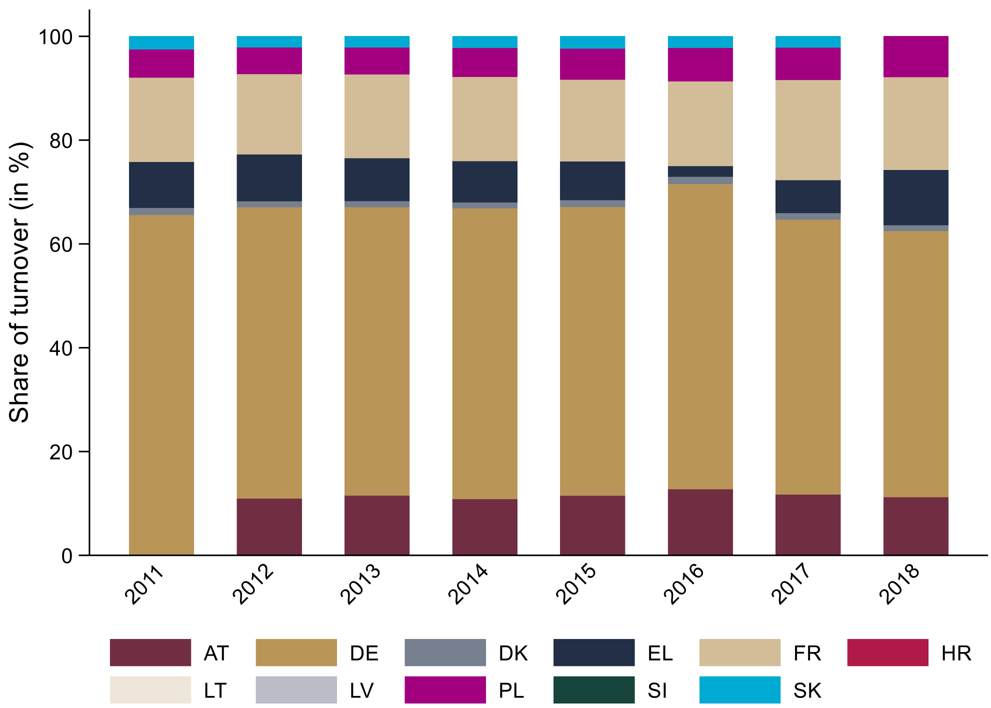
85% ex (1.5ct)	0.0	-3.4	-3.3	0.0	-1.2				-0.7	-4.9	0.0
85% ex cond. (1.5ct)	0.0	-7.8	-3.3	0.0	-6.2				-0.7	-4.9	0.0
75% ex (2ct)	0.0	-5.9	-3.3	0.0	-2.3				-0.7	-4.9	0.0
75% ex cond. (2ct)	0.0	-10.4	-3.3	0.0	-7.7				-0.7	-4.9	0.0
85% ex (2ct)	0.0	-3.4	-3.3	0.0	-1.2				-0.7	-4.9	0.0
85% ex cond. (2ct)	0.0	-9.1	-3.3	0.0	-7.6				-0.7	-4.9	0.0
Turnover (M. euro)	8168	38388		492	15001				7041	749	3045

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.8 Aluminium production

"Aluminium production" (NACE C24.42) is a sector located mainly in Germany and France, and smaller turnover shares come from Austria, Greece, Poland and Slovenia, out of all EU-11 countries. The following chart depicts annual turnover shares by country.

Figure 105: Share of EU-11 turnover by country for aluminium production



Source: Eurostat.

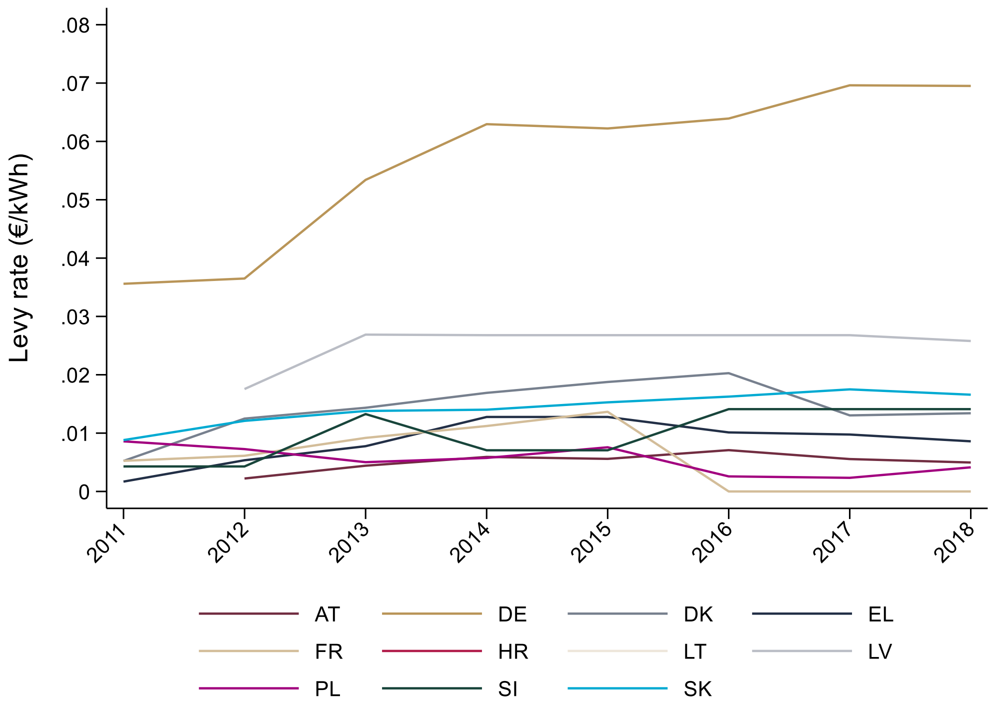
The sector has the EU-11 average electro-intensity of 41.33%. It is listed in Annex 3 of the EEAG. Electro-intensity varies significantly among the firms in the sector. Primary aluminium production requires large quantities of electricity for smelting alumina in an electrolytic process. On the other hand, the secondary aluminium production (i.e. recycling of scrap) requires only 5% of the energy needed for primary aluminium production. Thus, depending on the proportions of both types of aluminium producers, the average electro-intensity can differ significantly from country to country.[365] A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Denmark, France, Germany, Poland and Slovenia. The degree of pass-on of cost increase indicated by the sector fiche was zero.[366] This is due to the trade of aluminium in the London Metals Exchange (LME). We therefore quantify the pass-on with 0. Five other sectors from the same NACE 3-digit sector C24.4 are all listed in Annex 3 of the EEAG:

- Precious metals production (NACE code C24.41);
- Lead, zinc and tin production (NACE code C24.43);
- Copper production (NACE code C24.44);
- Other non-ferrous metal production (NACE code C24.45);
- Processing of nuclear fuel (NACE code C24.46).

Annex 19.8.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in aluminium production were calculated over time before deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levy types per country.

Figure 106: RES and CHP levies without reductions in aluminium production

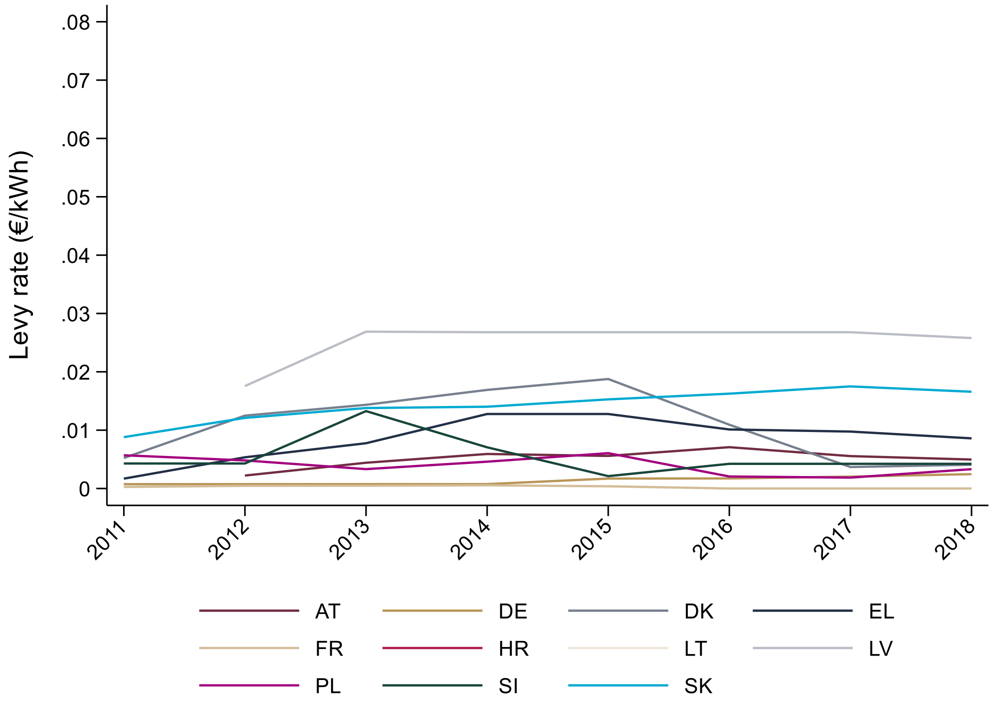


Source: Support study. European Commission, Eurostat, and own calculations.

[365] "Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Aluminium production.

[366] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Aluminium production.

Figure 107: RES and CHP effective levies in aluminium production

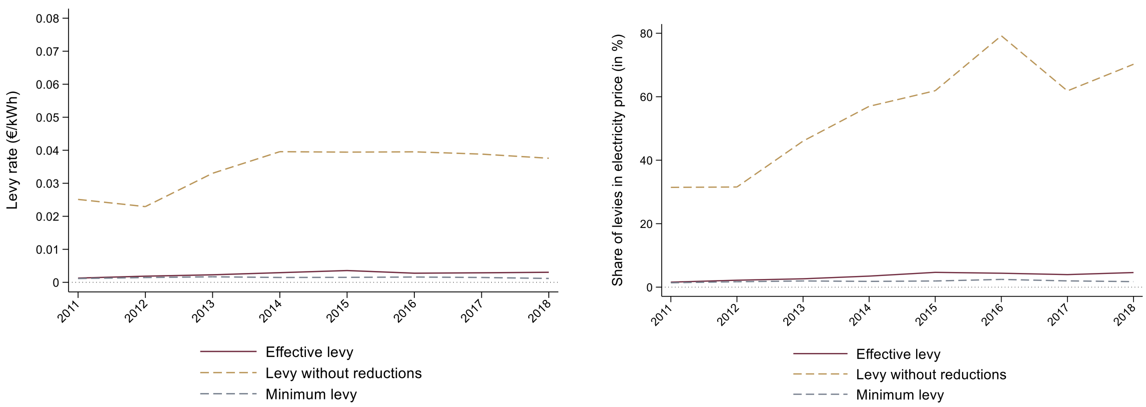


Source: Support study. European Commission, Eurostat, and own calculations.

Comparing the levy for Germany in the above two figures, it is clear that the exemptions bring the levy in Germany to the level similar to other EU-11 countries. The highest levy without reductions is in Germany in every year, but the highest effective levy is in Slovakia (2011, 2016-2018) und Denmark (2012-2015). The lowest levies without exemptions are paid in Greece (2011), Austria (2012-2015) and France (as of 2016), for effective levies it is Germany (until 2013) and France (as of 2014), matched by Slovenia in 2015.

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 108: EU-11 average RES and CHP levy and its share in the electricity bill in aluminium production



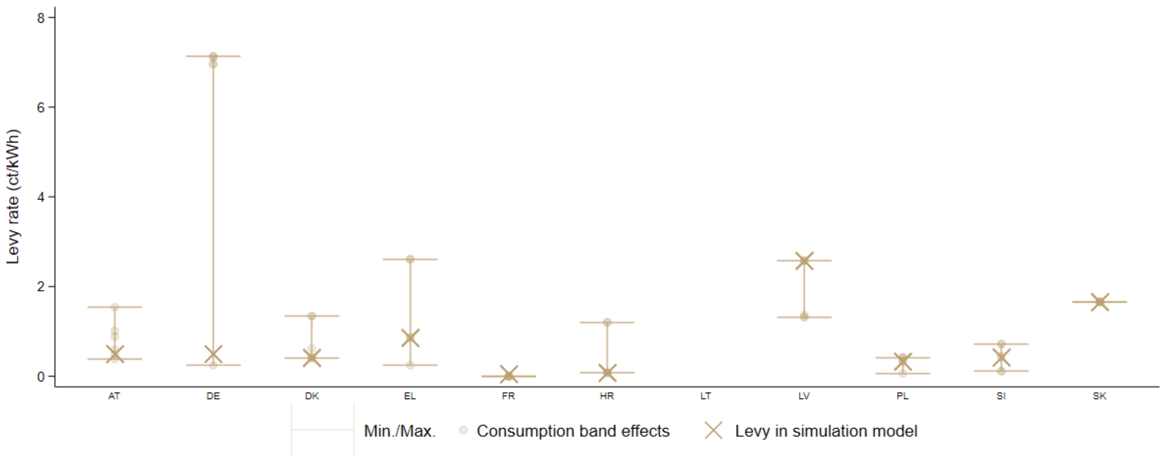
Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 levies without reductions increase from about 25% of electricity price in 2011 to almost 50% in 2018. The exemptions reduce the paid levies very strongly to below 10%

level. The effective levy is flat over time with a shift in 2014, which reflects the increase of effective levies in Germany and in Greece.

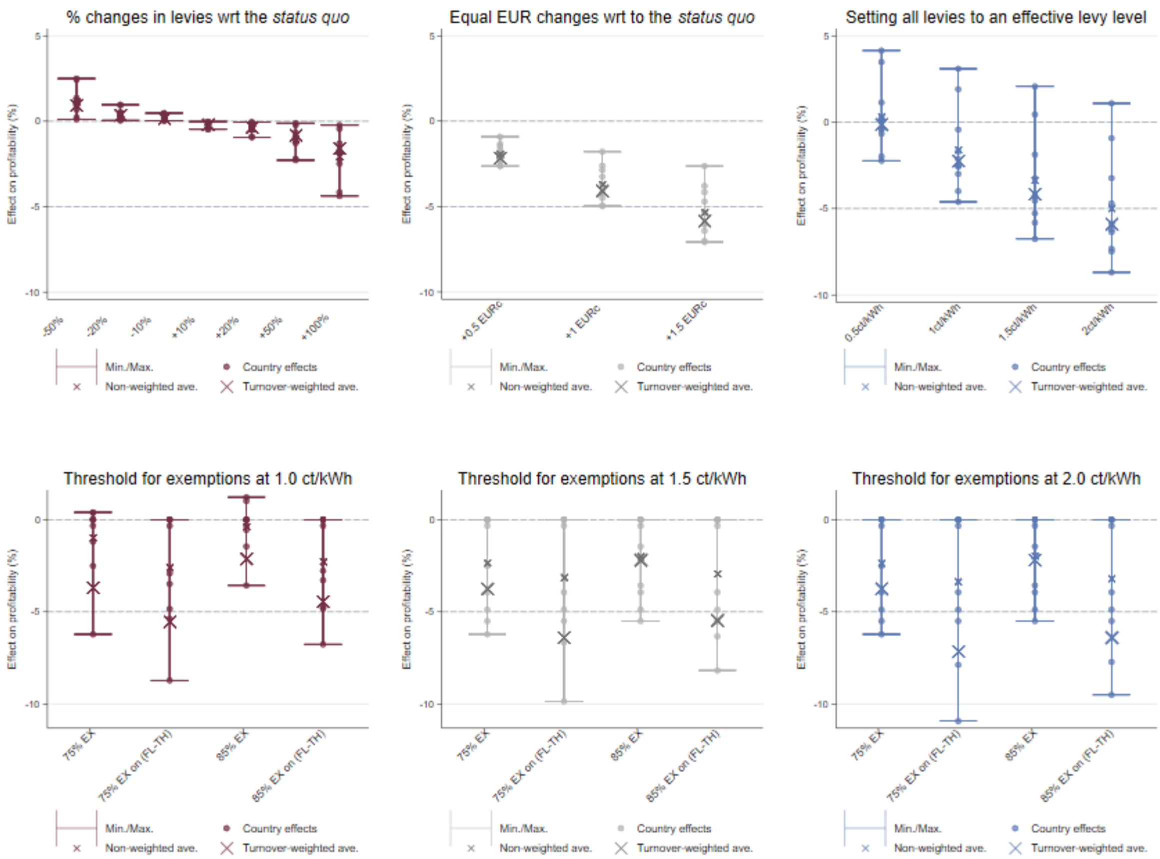
Annex 19.8.2 Detailed sectoral results from simulation model

Figure 109: Effective levy rate in 2018 per consumption band in aluminium



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 110: Simulated profitability changes (%) per scenario for aluminium



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 76: Simulated EU-11 average profitability changes (in %) for aluminium

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-16.3	-17.8	-21.5	-7.0
	No exemptions	-4.3	-11.5	-19.0	0.0
% Changes to levies	-50%	1.2	1.0	0.1	2.5
	-20%	0.5	0.4	0.0	1.0
	-10%	0.2	0.2	0.0	0.5
	+10%	-0.2	-0.2	-0.5	0.0
	+20%	-0.4	-0.3	-0.9	0.0
	+50%	-1.1	-0.8	-2.3	-0.1
	+100%	-2.1	-1.6	-4.4	-0.2
Absolute changes in levies	+0.5 ct	-1.9	-2.1	-2.6	-0.9
	+1.0 ct	-3.7	-4.1	-5.0	-1.8
	+1.5 ct	-5.3	-5.8	-7.1	-2.6
Setting the effective levy	0.5ct	0.3	-0.1	-2.2	4.2
	1ct	-1.6	-2.2	-4.6	3.1
	1.5ct	-3.4	-4.1	-6.8	2.1
	2ct	-5.0	-5.9	-8.7	1.1
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.9	-3.7	-6.2	0.4
	75% ex on amount above TH	-2.6	-5.5	-8.7	0.0
	85% ex on full levy	-0.4	-2.1	-3.6	1.2
	85% ex on amount above TH	-2.3	-4.4	-6.8	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-2.3	-3.7	-6.2	0.0
	75% ex on amount above TH	-3.1	-6.4	-9.9	0.0
	85% ex on full levy	-2.0	-2.2	-5.5	0.0
	85% ex on amount above TH	-2.9	-5.5	-8.2	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-2.3	-3.7	-6.2	0.0
	75% ex on amount above TH	-3.3	-7.1	-10.9	0.0

	85% ex on full levy	-2.0	-2.2	-5.5	0.0
	85% ex on amount above TH	-3.2	-6.4	-9.5	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 77: Simulated average profitability changes (in %) for aluminium by country

Exp	AT	DE	DK	EL	FR	HR	LT	LV	PL	SI	SK
HI	-15.2	-19.0	-18.8	-13.3	-19.0	-21.5		-7.0	-17.3	-20.5	-11.0
No EX	0.0	-19.0	-3.9	0.0	-9.0	-5.5		0.0	-0.3	-4.9	0.0
-50%	0.9	1.2	1.0	1.4	0.1	0.2		2.5	0.7	1.2	2.4
-20%	0.4	0.4	0.4	0.5	0.0	0.1		1.0	0.3	0.5	0.9
-10%	0.2	0.2	0.2	0.3	0.0	0.0		0.5	0.1	0.2	0.5
+10%	-0.2	-0.2	-0.2	-0.3	0.0	0.0		-0.5	-0.1	-0.2	-0.5
+20%	-0.3	-0.4	-0.4	-0.5	0.0	-0.1		-0.9	-0.3	-0.5	-0.9
+50%	-0.9	-1.0	-0.9	-1.3	-0.1	-0.2		-2.3	-0.7	-1.1	-2.2
+100%	-1.7	-1.8	-1.8	-2.5	-0.2	-0.4		-4.4	-1.3	-2.2	-4.2
+0.5 ct	-1.7	-2.4	-2.2	-1.5	-2.2	-2.6		-0.9	-1.9	-2.6	-1.3
+1.0 ct	-3.3	-4.5	-4.2	-2.9	-4.2	-5.0		-1.8	-3.7	-4.9	-2.6
+1.5 ct	-4.7	-6.4	-6.1	-4.2	-6.0	-7.1		-2.6	-5.3	-7.0	-3.8
0.5ct (eff. l.)	0.0	0.2	-0.4	1.1	-2.0	-2.2		4.2	-0.7	-0.4	3.5
1ct (eff. l.)	-1.7	-2.1	-2.6	-0.4	-4.0	-4.6		3.1	-2.5	-3.0	1.9
1.5ct (eff. l.)	-3.2	-4.3	-4.5	-1.9	-5.8	-6.8		2.1	-4.3	-5.3	0.4
2ct (eff. l.)	-4.7	-6.2	-6.4	-3.2	-7.5	-8.7		1.1	-5.9	-7.3	-0.9
75% ex (1ct)	0.0	-6.2	0.4	0.0	-2.5	-1.2		0.0	-0.3	0.4	0.0
75% ex cond. (1ct)	0.0	-8.7	-2.9	0.0	-5.4	-4.8		0.0	-0.3	-3.5	0.0
85% ex (1ct)	0.0	-3.6	1.0	0.0	-1.5	-0.6		0.0	-0.3	1.2	0.0
85% ex cond. (1ct)	0.0	-6.8	-2.8	0.0	-4.8	-4.7		0.0	-0.3	-3.3	0.0
75% ex (1.5ct)	0.0	-6.2	-3.9	0.0	-2.5	-5.5		0.0	-0.3	-4.9	0.0
75% ex cond. (1.5ct)	0.0	-9.9	-3.9	0.0	-6.7	-5.5		0.0	-0.3	-4.9	0.0
85% ex (1.5ct)	0.0	-3.6	-3.9	0.0	-1.5	-5.5		0.0	-0.3	-4.9	0.0

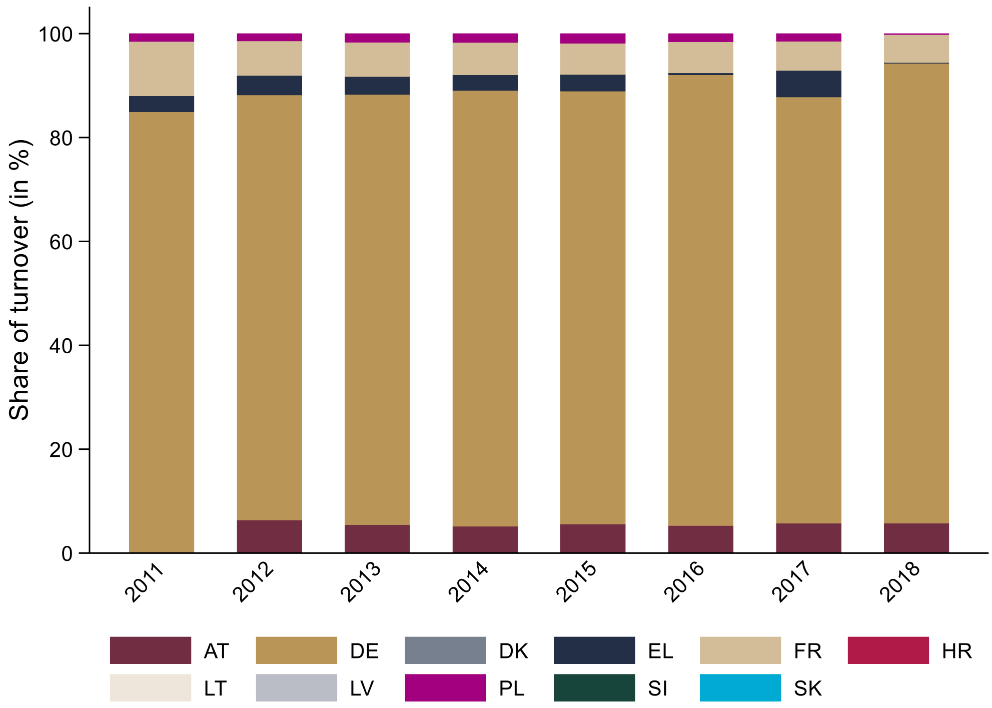
85% ex cond. (1.5ct)	0.0	-8.2	-3.9	0.0	-6.3	-5.5		0.0	-0.3	-4.9	0.0
75% ex (2ct)	0.0	-6.2	-3.9	0.0	-2.5	-5.5		0.0	-0.3	-4.9	0.0
75% ex cond. (2ct)	0.0	-10.9	-3.9	0.0	-7.9	-5.5		0.0	-0.3	-4.9	0.0
85% ex (2ct)	0.0	-3.6	-3.9	0.0	-1.5	-5.5		0.0	-0.3	-4.9	0.0
85% ex cond. (2ct)	0.0	-9.5	-3.9	0.0	-7.7	-5.5		0.0	-0.3	-4.9	0.0
Turnover (M. euro)	3402	15434	353	2565	5493	39			2101		594

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.9 Copper production

"Copper production" (NACE 24.44) is a sector located mainly in Germany, with only small turnover coming from Austria, Greece, France and Poland, out of all EU-11 countries. The following chart depicts annual turnover shares by country.

Figure 111: Share of EU-11 turnover by country for copper production



Source: Eurostat.

The sector has the average electro-intensity of 18.11%. Such a relatively low average electro-intensity may be the result of large heterogeneity of firms in the sector. Copper production is done by smelters and refineries, but smelters consume 2.75 times more electricity per tonne of copper than refineries.[367] In addition, firms in the secondary copper

[367] Aikaterini Boulamanti, Jose Antonio Moya, "Production costs of the non-ferrous metals in the EU and other countries: Copper and zinc," Resources Policy, Volume 49, 2016, pages 112-118.

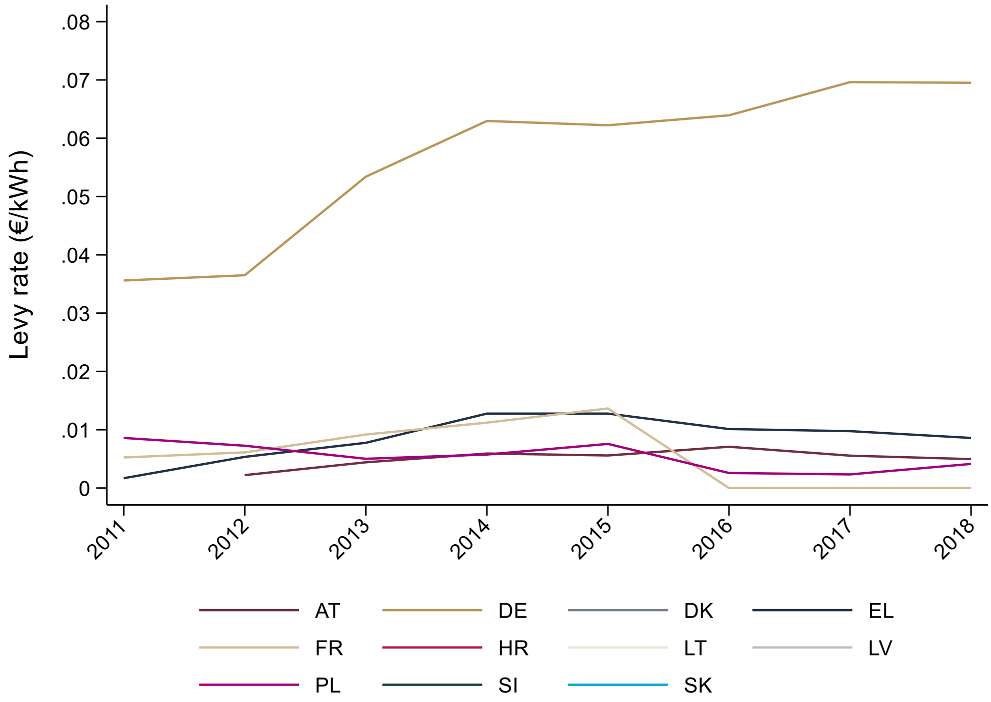
production (recycling), which meet about 50% of the EU copper demand, can be up to 85% more energy-efficient than primary copper production.[368] The sector is listed in Annex 3 of the EEAG. A firm with the country-specific sector's EU-11 average electro-intensity and electricity consumption was eligible for RES and CHP levy exemptions in Poland only. The degree of pass-on of cost increase indicated by the sector fiche was zero.[369] This is due to the trade of copper in the London Metals Exchange (LME). We therefore quantify the pass-on with 0. Five other sectors from the same NACE 3-digit sector C24.4 are all listed in Annex 3 of the EEAG:

- Precious metals production (NACE code C24.41);
- Aluminium production (NACE code C24.42);
- Lead, zinc and tin production (NACE code C24.43);
- Other non-ferrous metal production (NACE code C24.45);
- Processing of nuclear fuel (NACE code C24.46).

Annex 19.9.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in copper production were calculated over time before deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levy types per country.

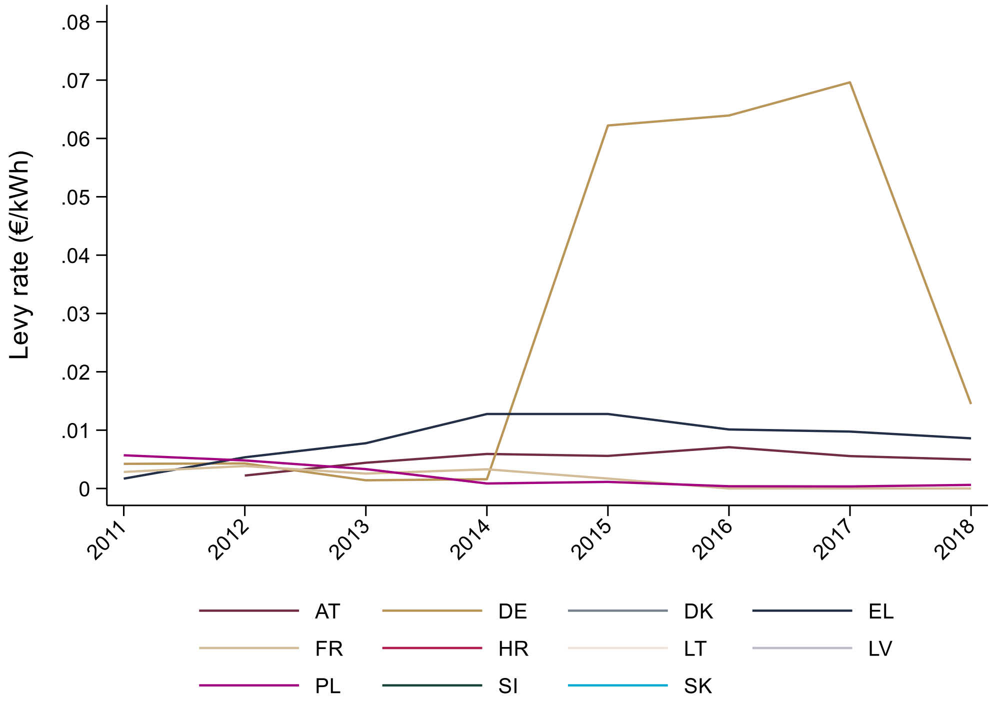
Figure 112: RES and CHP levies without reductions in copper production



Source: Support study. European Commission, Eurostat, and own calculations.

[368] See https://copperalliance.eu/benefits-of-copper/recycling/ viewed on 12th December 2020.
[369] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Copper production.

Figure 113: RES and CHP effective levies in copper production

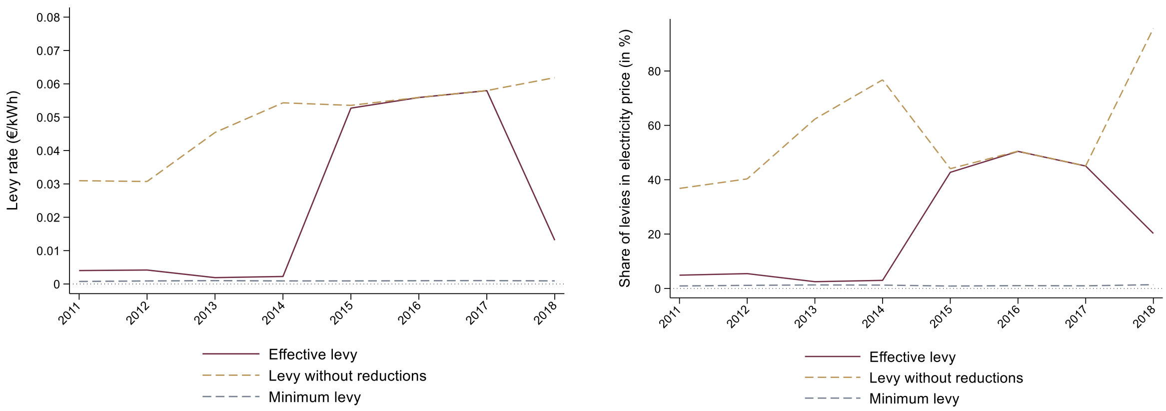


Source: Support study. European Commission, Eurostat, and own calculations.

The levy in Germany is the highest both before and after the reductions. This is because a firm with the average electro-intensity is not eligible for reductions in Germany. The lowest levy without reductions is in Greece, Austria and France. The lowest effective levy is in Greece (2011), Austria (2012), Poland (2013-2015) and France (as of 2016).

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 114: EU-11 average RES and CHP levy and its share in the electricity bill in copper production

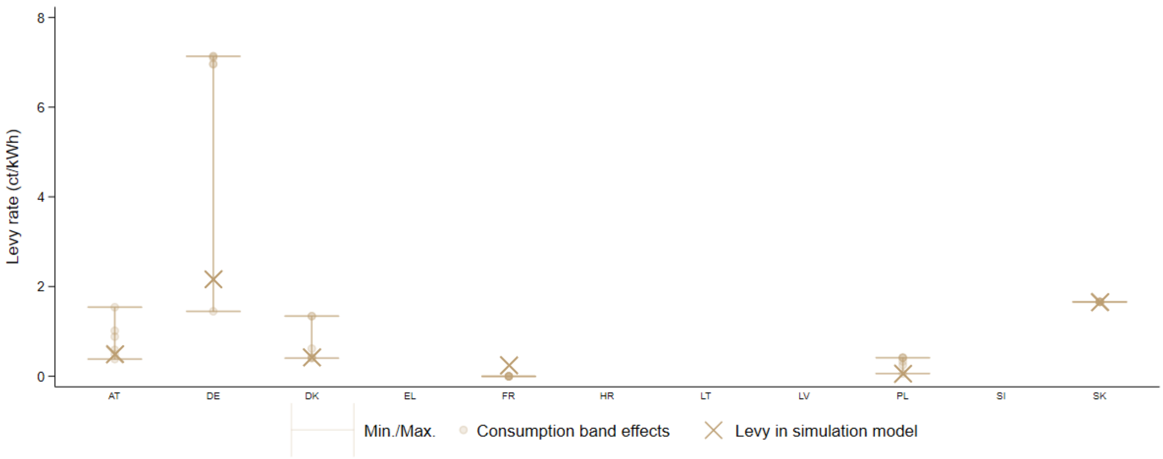


Source: Own calculation based on data from the support study, European Commission and Eurostat.

The EU-11 average effective levy for an average firm in copper production doubled from 0.03 to 0.06 €/kWh 2011-2018. It follows the levy development in Germany very closely, reflecting the turnover share for Germany exceeding 80%. Levy exemptions have almost no impact on the effective levy paid. The EU-11 average share of effective levy in the electricity price rose from about 30% in 2011 to almost 70% in 2018.

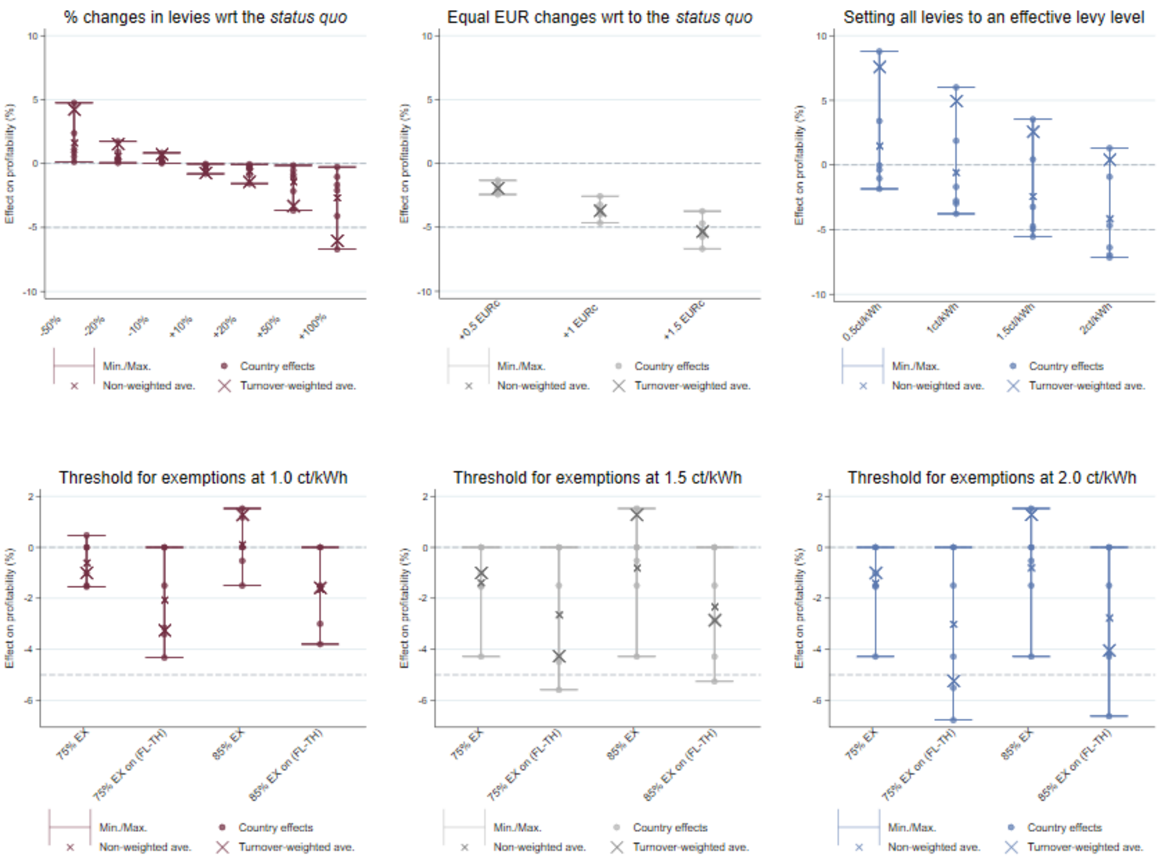
Annex 19.9.2 Detailed sectoral results from simulation model

Figure 115: Effective levy rate in 2018 per consumption band in copper



Source: Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 116: Simulated profitability changes (%) per scenario for copper



Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies.

Table 78: Simulated EU-11 average profitability changes (in %) for copper

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-16.0	-13.6	-20.9	-11.0
	No exemptions	-4.5	-12.0	-13.2	0.0
% Changes to levies	-50%	1.6	4.2	0.1	4.7
	-20%	0.6	1.5	0.1	1.7
	-10%	0.3	0.8	0.0	0.8
	+10%	-0.3	-0.7	-0.8	0.0
	+20%	-0.6	-1.4	-1.6	-0.1
	+50%	-1.4	-3.3	-3.7	-0.1
	+100%	-2.6	-6.0	-6.7	-0.3
Absolute changes in levies	+0.5 ct	-1.9	-1.9	-2.4	-1.3
	+1.0 ct	-3.7	-3.7	-4.6	-2.6
	+1.5 ct	-5.3	-5.3	-6.7	-3.7
Setting the effective levy	0.5ct	1.5	7.6	-1.8	8.8
	1ct	-0.6	5.0	-3.8	6.0
	1.5ct	-2.4	2.6	-5.5	3.5
	2ct	-4.1	0.4	-7.1	1.3
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.6	-1.0	-1.5	0.5
	75% ex on amount above TH	-2.1	-3.2	-4.3	0.0
	85% ex on full levy	0.1	1.3	-1.5	1.5
	85% ex on amount above TH	-1.6	-1.6	-3.8	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-1.4	-1.0	-4.3	0.0
	75% ex on amount above TH	-2.6	-4.3	-5.6	0.0
	85% ex on full levy	-0.8	1.3	-4.3	1.5
	85% ex on amount above TH	-2.3	-2.8	-5.3	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-1.4	-1.0	-4.3	0.0
	75% ex on amount above TH	-3.0	-5.2	-6.8	0.0

	85% ex on full levy	-0.8	1.3	-4.3	1.5
	85% ex on amount above TH	-2.8	-4.0	-6.6	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios.

Table 79: Simulated average profitability changes (in %) for copper by country

Exp	**AT**	**DE**	**DK**	**EL**	**FR**	**HR**	**LT**	**LV**	**PL**	**SI**	**SK**
HI	-15.1	-13.2	-20.9		-17.8				-18.4		-11.0
No EX	0.0	-13.2	-4.3		-7.9				-1.5		0.0
-50%	0.9	4.7	1.1		0.5				0.1		2.4
-20%	0.3	1.7	0.4		0.2				0.1		0.9
-10%	0.2	0.8	0.2		0.1				0.0		0.5
+10%	-0.2	-0.8	-0.2		-0.1				0.0		-0.4
+20%	-0.3	-1.6	-0.4		-0.2				-0.1		-0.9
+50%	-0.9	-3.7	-1.1		-0.5				-0.1		-2.1
+100%	-1.7	-6.7	-2.1		-1.0				-0.3		-4.1
+0.5 ct	-1.7	-1.9	-2.4		-2.0				-2.1		-1.3
+1.0 ct	-3.2	-3.7	-4.6		-3.9				-4.0		-2.6
+1.5 ct	-4.7	-5.3	-6.7		-5.6				-5.7		-3.7
0.5ct (eff. l.)	0.0	8.8	-0.4		-1.0				-1.8		3.4
1ct (eff. l.)	-1.7	6.0	-2.8		-3.0				-3.8		1.9
1.5ct (eff. l.)	-3.2	3.5	-5.0		-4.8				-5.5		0.4
2ct (eff. l.)	-4.7	1.3	-7.0		-6.4				-7.1		-0.9
75% ex (1ct)	0.0	-1.0	0.5		-1.5				-1.5		0.0
75% ex cond. (1ct)	0.0	-3.4	-3.2		-4.3				-1.5		0.0
85% ex (1ct)	0.0	1.5	1.2		-0.5				-1.5		0.0
85% ex cond. (1ct)	0.0	-1.5	-3.0		-3.8				-1.5		0.0
75% ex (1.5ct)	0.0	-1.0	-4.3		-1.5				-1.5		0.0
75% ex cond. (1.5ct)	0.0	-4.5	-4.3		-5.6				-1.5		0.0
85% ex (1.5ct)	0.0	1.5	-4.3		-0.5				-1.5		0.0
85% ex cond. (1.5ct)	0.0	-2.9	-4.3		-5.3				-1.5		0.0

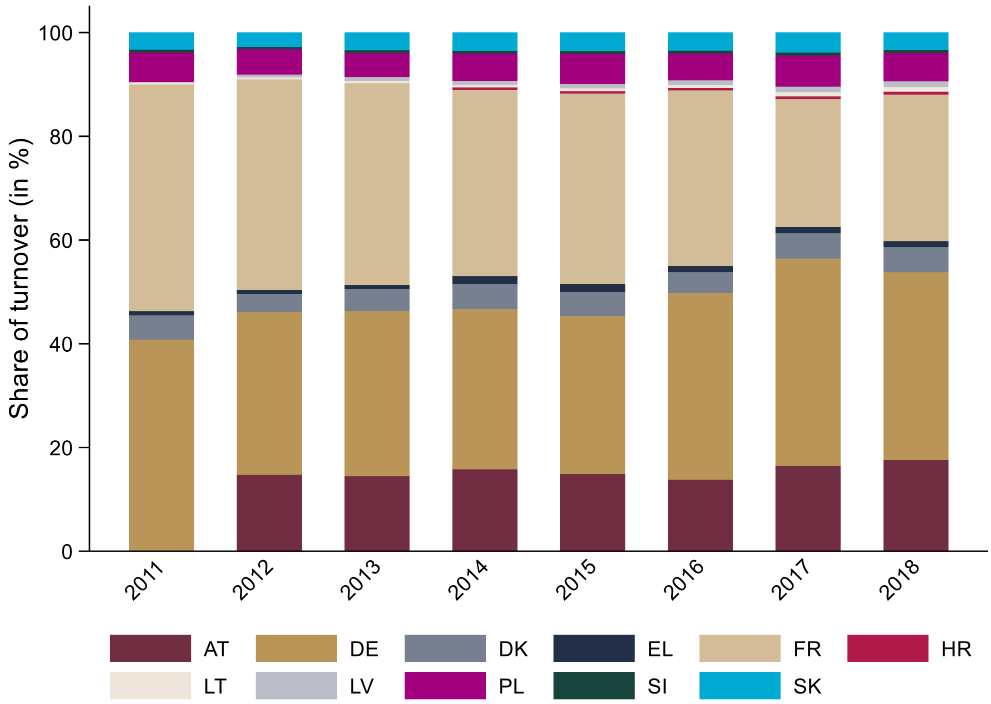
75% ex (2ct)	0.0	-1.0	-4.3	-1.5	-1.5	0.0
75% ex cond. (2ct)	0.0	-5.5	-4.3	-6.8	-1.5	0.0
85% ex (2ct)	0.0	1.5	-4.3	-0.5	-1.5	0.0
85% ex cond. (2ct)	0.0	-4.1	-4.3	-6.6	-1.5	0.0
Turnover (M. euro)	1086	16124		1043	154	

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios.

Annex 19.10 Data processing, hosting and related activities

"Data processing, hosting and related activities" (NACE J63.11) is a sector located mainly in Germany, France, Austria, Poland, Denmark, Slovakia and a few countries with a very small turnover share, out of the EU-11 countries. The following chart depicts annual turnover shares by country.

Figure 117: Share of EU-11 turnover by country for data processing, hosting and related activities



Source: Eurostat.

Electricity consumption data for this sector provided by the Commission was available only for Greece. Thus, the sector information from the study by Trinomics et al. (2020) was used as a source of estimated electricity cost in the more aggregated 3-digit sector J63.1 "Data processing, hosting and related activities; Web portals". For the EU27 in year 2017 the electricity cost in the sector amounted to 4,8 € billion.[370] Value added at factor cost provided by Eurostat for the sector was 30 € bn (EU27 in 2018, the figure for 2017 is

[370] Study on energy prices, costs and their impact on industry and households. Final report for the European Commission. Trinomics, Enerdata, Cambridge Econometrics, LBST, 2020, page 322.

confidential). Dividing electricity cost by the value added gives a proxy of the sector's electro-intensity of 16%. This electro-intensity is likely to be representative for the 4-digit sector J63.11, because it accounts for 75%[371] of the gross value added in the sector J63.1. The consumption band identified for the sector J63.1 by the study is IE.[372]

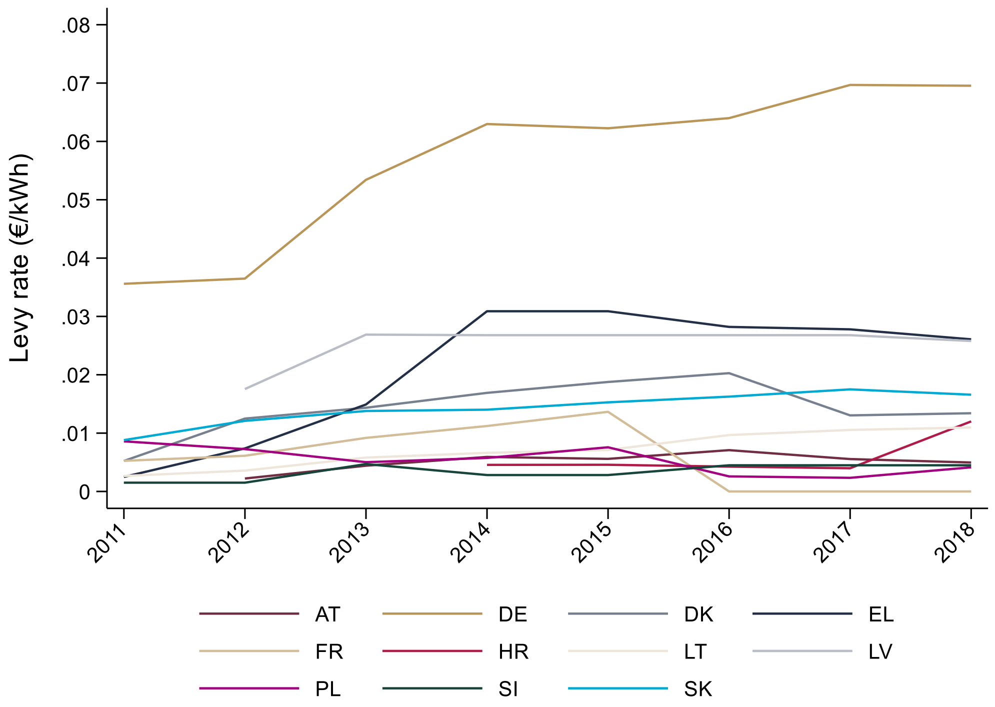
The degree of pass-on of cost increase indicated by the sector fiche was medium[373] and we quantified it with 0.5.

The J63.11 sector is not listed in any Annex of the EEAG. A firm from this sector with the average electro-intensity of 16% and an average electricity consumption in band IE was eligible for RES and CHP levy exemptions in France, Germany (until 2013) and Poland. Another sector in the same 3-digit sector is Web portals (NACE J63.12).

Annex 19.10.1 RES/CHP levies for a firm with average electricity consumption

RES and CHP levies paid by a firm with the average electricity consumption in each country in data processing, hosting and related activities were calculated over time before deducting the exemptions (levies without reductions) and after deducting the exemptions (effective levies). The following figures depict the time-development of both levy types per country.

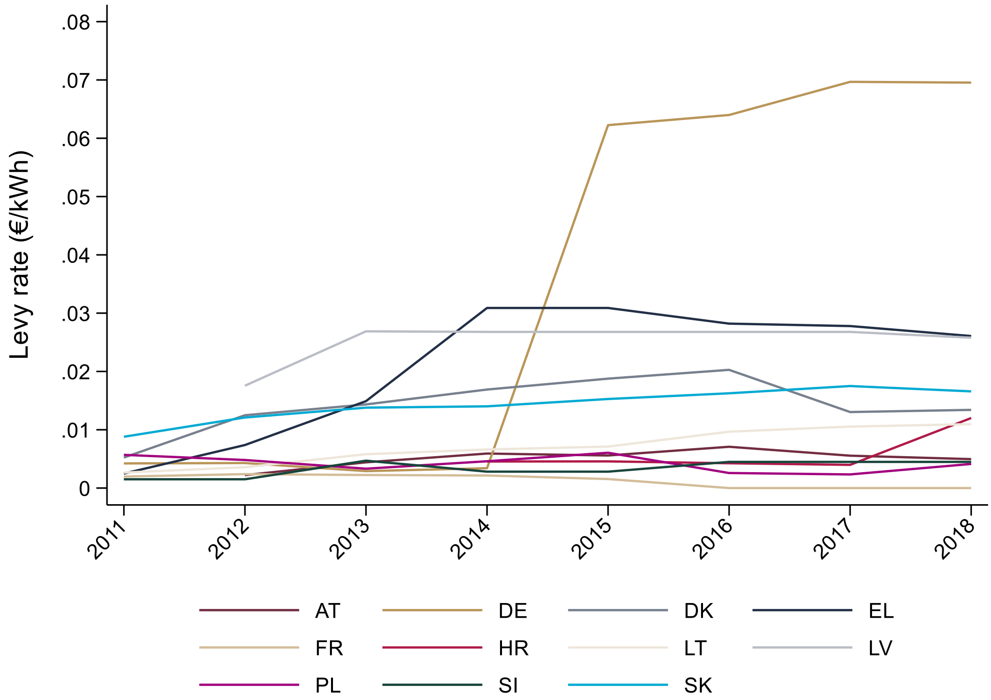
Figure 118: RES and CHP levies without reductions in data processing, hosting and related activities



Source: Support study. European Commission, Eurostat, and own calculations.

[371] Based on Eurostat's SBS database, the gross value added in the 4-digit sector J63.11 amounts to 22.452€ bn, which is roughly 75% of the gross value added in the 3-digit sector J63.1.
[372] Trinomics et al., (2020), page 321.
[373] Combined retrospective evaluation and prospective impact assessment support study on Emission Trading System (ETS) State Aid Guidelines." Final report by ADE and Compass Lexecon, October 2020. Sector Fiche: Data processing, hosting and related activities.

Figure 119: RES and CHP effective levies in data processing, hosting and related activities

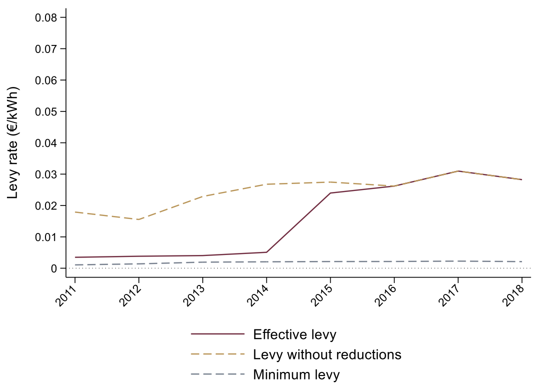


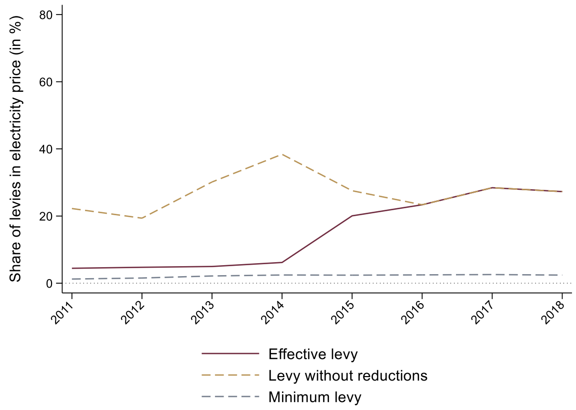
Source: Support study. European Commission, Eurostat, and own calculations.

The highest levy without exemptions for the sector in all years was in Germany. The exemptions reduced it significantly in the years 2011-2013, but starting with 2014 the sector did not quality for exemptions in Germany anymore and the highest levies had to be paid in this country. The lowest levies without exemptions were paid in Slovenia (2011-2015) and France (2016-2018). The effective levies were lowest in Slovenia (2011-2012, 2014-2015), Germany and Poland in 2013, and France (2016-2018).

The following figure presents the development of the EU-11 average RES and CHP without reductions and effective (on the left) and their share in the electricity price for the sector (on the right).

Figure 120: EU-11 average RES and CHP levy and its share in the electricity bill in data processing, hosting and related activities



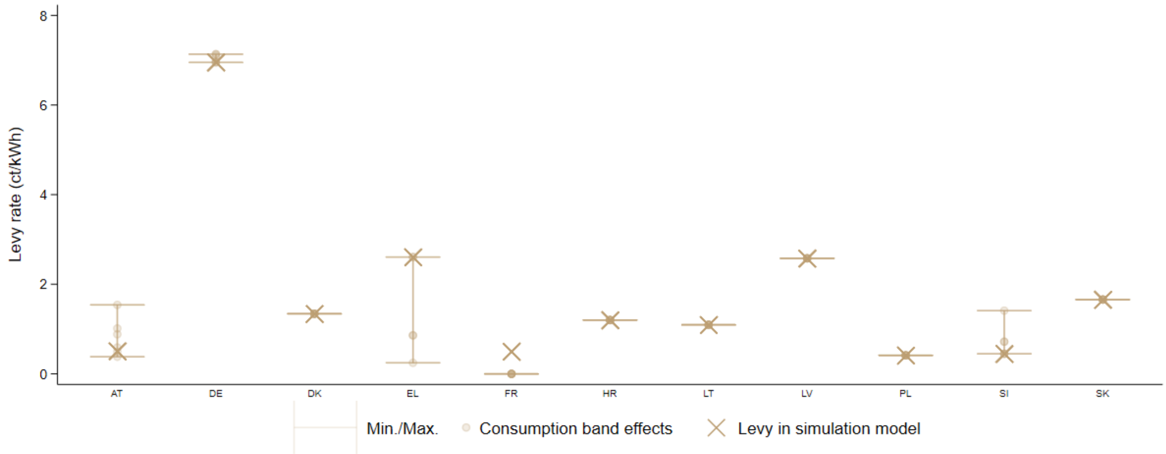


Source: Own calculation based on data from the support study, European Commission and Eurostat.

Effective EU-11 average levies paid by the sector of data processing, hosting and related activities, were relatively low below 0.01 €/kWh in the years 2011-2013, due to large exemptions in Germany. Since 2014, hardly any effect of exemptions can be observed and the effective levy increased between 2014 and 2017 to almost 0.03 €/kWh and dropped slightly in 2018. The share of levies in the EU-11 average electricity price for the sector rose from below 10% in 2011 to more than 30% in 2018.

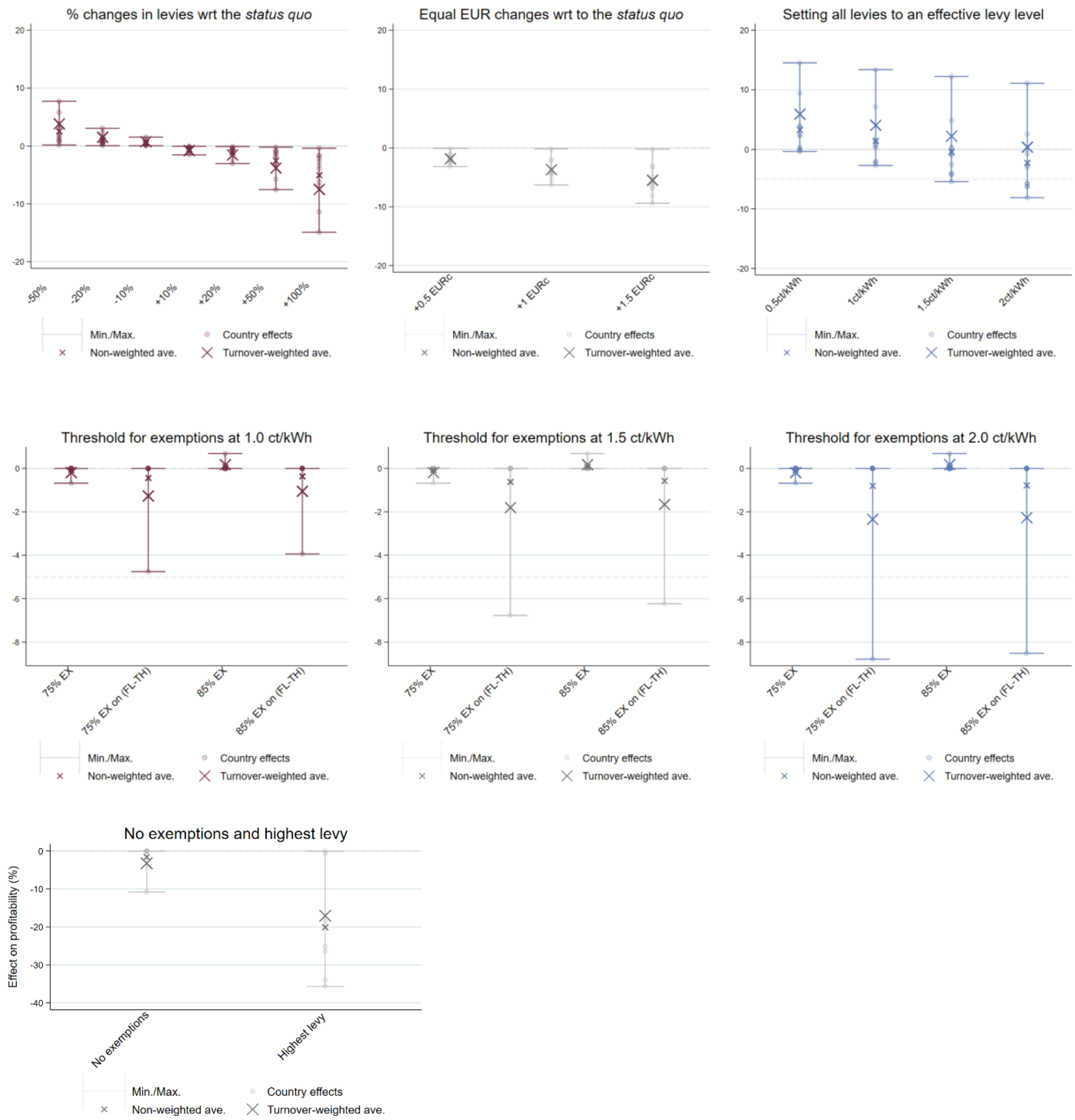
Annex 19.10.2 Detailed sectoral results from simulation model

Figure 121: Effective levy rate in 2018 per consumption band in data hosting



Source: The Support study, European Commission, Eurostat, Amadeus and own calculations.

Figure 122: Simulated profitability changes (%) per scenario for data hosting from the static model



Source: The Support study, European Commission, Eurostat, Amadeus and own calculations. The levy changes were based on estimated levy changes from the estimation framework, but the changes in profitability were calculated using the static model. In the static model framework, profitability is defined as gross operating surplus divided by turnover.

Table 80: Simulated EU-11 average profitability changes (in %) for data processing

	Experiment	Average non-weighted	Average turnover-weighted	Minimum effect across countries	Maximum effect across countries
Unexempted levy or highest levy	Highest sector-specific levy	-19.9	-17.3	-35.7	0.0
	No exemptions	-1.0	-2.9	-10.8	0.0

% Changes to levies	-50%	2.6	3.9	0.2	7.7
	-20%	1.0	1.5	0.1	3.1
	-10%	0.5	0.8	0.0	1.5
	+10%	-0.5	-0.8	-1.5	0.0
	+20%	-1.0	-1.5	-3.0	-0.1
	+50%	-2.5	-3.8	-7.5	-0.2
	+100%	-5.0	-7.5	-14.9	-0.4
Absolute changes in levies	+0.5 ct	-1.8	-1.8	-3.2	-0.1
	+1.0 ct	-3.7	-3.7	-6.3	-0.1
	+1.5 ct	-5.5	-5.5	-9.4	-0.2
Setting the effective levy	0.5ct	3.3	5.9	-0.3	14.5
	1ct	1.4	4.1	-2.7	13.4
	1.5ct	-0.4	2.2	-5.4	12.2
	2ct	-2.2	0.4	-8.1	11.1
Threshold for exemptions at 1ct/kWh	75% ex on full levy	-0.1	-0.2	-0.7	0.0
	75% ex on amount above TH	-0.4	-1.3	-4.7	0.0
	85% ex on full levy	0.1	0.2	0.0	0.7
	85% ex on amount above TH	-0.4	-1.0	-3.9	0.0
Threshold for exemptions at 1.5ct/kWh	75% ex on full levy	-0.1	-0.2	-0.7	0.0
	75% ex on amount above TH	-0.6	-1.8	-6.8	0.0
	85% ex on full levy	0.1	0.2	0.0	0.7
	85% ex on amount above TH	-0.6	-1.7	-6.2	0.0
Threshold for exemptions at 2ct/kWh	75% ex on full levy	-0.1	-0.2	-0.7	0.0
	75% ex on amount above TH	-0.8	-2.3	-8.8	0.0
	85% ex on full levy	0.1	0.2	0.0	0.7
	85% ex on amount above TH	-0.8	-2.3	-8.5	0.0

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. The turnover weighted average does not include countries without turnover. See the table below for information about the affected countries. See Section 3.5.2 for more details about the scenarios and Section 3.5.3 for more details about the static model.

Table 81: Simulated average profitability changes (in %) for data processing by country

Exp	AT	DE	DK	EL	FR	HR	LT	LV	PL	SI	SK
HI	-26.4	0.0	-25.2	-0.6	-34.0	-18.5	-35.7	-19.1	-25.0	-23.8	-10.6
No EX	0.0	0.0	0.0	0.0	-10.8	0.0	0.0	0.0	0.0	0.0	0.0
-50%	1.1	7.7	3.1	0.2	1.4	2.0	3.5	5.8	0.8	0.9	1.7
-20%	0.4	3.1	1.2	0.1	0.5	0.8	1.4	2.3	0.3	0.3	0.7
-10%	0.2	1.5	0.6	0.0	0.3	0.4	0.7	1.2	0.2	0.2	0.3
+10%	-0.2	-1.5	-0.6	0.0	-0.3	-0.4	-0.7	-1.2	-0.2	-0.2	-0.3
+20%	-0.4	-3.0	-1.2	-0.1	-0.5	-0.8	-1.4	-2.3	-0.3	-0.3	-0.7
+50%	-1.1	-7.5	-3.1	-0.2	-1.4	-2.0	-3.5	-5.7	-0.8	-0.8	-1.7
+100%	-2.1	-14.9	-6.1	-0.4	-2.7	-4.0	-6.9	-11.4	-1.6	-1.7	-3.4
+0.5 ct	-2.1	-1.1	-2.3	-0.1	-2.7	-1.7	-3.2	-2.2	-2.0	-1.9	-1.0
+1.0 ct	-4.2	-2.2	-4.6	-0.1	-5.4	-3.3	-6.3	-4.4	-3.9	-3.8	-2.0
+1.5 ct	-6.3	-3.3	-6.9	-0.2	-8.1	-5.0	-9.4	-6.7	-5.9	-5.6	-3.1
0.5ct (eff. l.)	0.0	14.5	3.9	0.3	0.0	2.4	3.8	9.4	-0.3	-0.2	2.4
1ct (eff. l.)	-2.1	13.4	1.6	0.2	-2.7	0.7	0.6	7.1	-2.3	-2.1	1.4
1.5ct (eff. l.)	-4.2	12.2	-0.7	0.2	-5.4	-1.0	-2.5	4.9	-4.3	-4.0	0.3
2ct (eff. l.)	-6.2	11.1	-3.0	0.1	-8.1	-2.7	-5.7	2.6	-6.2	-5.8	-0.7
75% ex (1ct)	0.0	0.0	0.0	0.0	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
75% ex cond. (1ct)	0.0	0.0	0.0	0.0	-4.7	0.0	0.0	0.0	0.0	0.0	0.0
85% ex (1ct)	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
85% ex cond. (1ct)	0.0	0.0	0.0	0.0	-3.9	0.0	0.0	0.0	0.0	0.0	0.0
75% ex (1.5ct)	0.0	0.0	0.0	0.0	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
75% ex cond. (1.5ct)	0.0	0.0	0.0	0.0	-6.8	0.0	0.0	0.0	0.0	0.0	0.0
85% ex (1.5ct)	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
85% ex cond. (1.5ct)	0.0	0.0	0.0	0.0	-6.2	0.0	0.0	0.0	0.0	0.0	0.0
75% ex (2ct)	0.0	0.0	0.0	0.0	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
75% ex cond. (2ct)	0.0	0.0	0.0	0.0	-8.8	0.0	0.0	0.0	0.0	0.0	0.0
85% ex (2ct)	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0

85% ex cond. (2ct)	0.0	0.0	0.0	0.0	-8.5	0.0	0.0	0.0	0.0	0.0	0.0
Turnover (M. euro)	3628	8061	1041	249	5637	117	181	230	1213	124	751

Source: Support study, European Commission, Eurostat, Amadeus and own calculations. All levy changes in the scenarios are calculated based on effective levies. See Section 3.5.2 for more details about the scenarios and Section 3.5.3 for more details about the static model.

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