Previous note: This text tries to highlight the important contradictions that can appear when putting into practice the two transformations digital and green, which the EU is about to carry out. The criticisms are made from the perspective of a Computer Science professional, with a certain experience in technical discussions within the framework of the Digitization calls. We will focus on Sector 7 of the Taxonomy that we think should constitute the nucleus of the inevitable intersection of the tasks that define each of the propos contents of the two transformations. As an example of the concern felt by the author, it should be noted that the European Council itself has recently and simultaneously cited in its conclusions its support for two policies that are incompatible in principle, on the one hand a defence of the Green Pact and on the other strongest recommendation to member states to support the Commission's efforts to consolidate Machine Learning and Blockchain in Europe when at the moment they are two technologies with computational expense that collapses the existing infrastructure and therefore supposes an unaffordable energy expense, with the current electricity mix in Europe.

The text has been prepared consulting the most reliable literature that I have had at my disposal, I hope more than enough, and most of the statements are supported by other authors. As I am unaware of the academic formality of the present type of document, I decided not to include any reference (I understand that we are not facing a review). If the reader considers that these references are necessary, he would try to find the time to include them in a later version.

CONTENT

SUMMARY

Digitalization is especially important for harder-to-decarbonize sectors such as heavy industry, aviation, and shipping, as it provides one of the few near-term opportunities to improve energy intensity and reduce the carbon impacts from these sectors as low-carbon alternatives are being developed. Digital energy innovation is vital to the future of the planet. Serious data and analysis are required to drive it. Half-baked arguments presented in the media that could derail it should be retired. Like all sectors, ICT has environmental costs. But these costs are frequently overstated, sometimes by a factor of 10 or more. Claims that "digital service X consumes as much electricity as country Y" should be viewed with scepticism. At best, they are misleading and lack context; at worst, they are wrong. The CO2 that can be emitted depends on three factors:

a) The demand for digital services that can be produced and that at the moment is very high. The control of the demand for these services, directly or indirectly, despite its importance, is not a subject considered in depth in the COM that have defined the two aforementioned transformations so far. This is a question that will appear in this text.

b) The mix of electrical energy that Europe and its territories have at any given time, which will determine the conversion of watts to milligrams of CO2. This is a factor that does not depend at all on any type of advance in the field of ICT, they are administrative, political and economic decisions.

c) Technological, scientific and engineering improvements that allow obtaining more digital productivity in terms of energy. This is an aspect that falls within the aforementioned Sector 7 of the Taxonomy.

The energy consumed by ICTs is used in three groups of activities:

a) The industrial sectors considered in the Taxonomy.

b) Services and products that existed before Digitization and that have been transformed thanks to ICT (e-commerce, e-health, etc.)

c) New products and services born under advanced Digitization (machine learning, new 5G applications, etc.)

Under these perspectives the criticisms would be:

- Update the task based on a bibliography that extrapolates very old data to locate the current situation of ICTs and their environmental impact in Europe.
- Do not mention objectives in terms of tons of CO2, limiting itself to expressing those in terms of electricity consumption.
- Reduce task 7.1 to data centres without mentioning user devices and networks (although it does recommend that the Commission do so in the future). This simplification leads to a very evident imbalance between the regions.
- Not taking into account the evolution of demand.
- In task 7.2, do not consider other applications that in any case would need a cost / benefit evaluation

INTRODUCTION

The contribution to the Green Pact of the Digital Industry is especially focused on reducing CO2 emissions (although it also does so to the rest of the GEG and to Biodivesity and the Environment). There is no doubt that the economic and computing activity related to the digital sector will ramp up faster in the present decade than in the last. Moreover, computing infrastructure is one of three major drivers of new electricity use alongside future and current hydrogen production and battery electric vehicles charging. Even more important, ICT is making energy systems smarter and more connected, using data analytics and advanced controls to improve energy efficiency and reduce the carbon intensity of buildings, manufacturing, transportation, and a host of other sectors.

The digital sector and its infrastructure – belonging to every activity of daily life - cannot easily be compared to other sectors. Moreover, different nations and different companies have totally different starting points regarding electric power infrastructure, growth of gross national product and nature of business growth. The current (2018-2020) big figures of the global energy situation of the entire digital sector (hypothetically having similar scale of power use as all kinds of computing/processing) into perspective being ≈3% of global primary energy consumption, ≈7% of global electricity use, and ≈5% of global CO2 emissions. The current share – and future evolution - of direct renewable electricity supply – beyond the local mix - to all global data centres and networks is not clear. The objective must be the trajectory in this decade for CO2 emissions associated with this digitalization and its share of electricity and energy generation as a whole.

Most of the world's Internet Protocol (IP) traffic goes through data centres. Greater connectivity is therefore propelling demand for data centre services and energy use (mostly electricity), with multiplying effects: for every bit of data that travels the network from data centres to end users, another five bits of data are transmitted within and among data centres.

Demand for data centre and network services will continue to grow strongly, driven in particular by rapidly growing demand from streaming video and gaming. Between 2019 and 2022, traffic from internet video is projected to more than double to 2.9 ZB, while online gaming is projected to quadruple to 180 EB. During the first weeks of the COVID pandemia (between February and mid-April 2020) global internet traffic surged by almost 40%, driven by growth in video streaming, video conferencing, online gaming, and social networking. This growth comes on top of rising demand for digital services over the past decade: since 2010, the number of internet users worldwide has doubled while global internet traffic has grown 12-fold

1. Digital industry

Although industry has to do with the transformation of one subject into others with the use of machines and procedures that increase GHGs, the machines and procedures of the digital sector also produce GHG, which is why in the literature they are located as an industry.

Digital services have potential, tenfold their footprint, to reduce energy and materials across the economy and could directly enable a third of the emissions reductions needed by 2030. We urgently need to explore how the digital industry can enable societal goals beyond the industry's narrow footprint. Exponential technologies risk driving emissions upwards as digital platforms improve behavioural prediction to drive consumer demand of unsustainable products and services. Moreover, social media platforms can help climate advocacy and engagement. However, they are also designed to accelerate the spread of emotionally charged information including disinformation – algorithmic propaganda. This is contributing to a rise in national populist movements that are often hostile to climate policies, international cooperation, and even science. The most significant risk from the digital revolution may not be artificial intelligence or biotechnology – it might be the inability for consumers and citizens to distinguish between fact and fiction. The ICT and E&M sectors will collectively be referred to as the "digital industry" – which is a subsection of the "industry" sector

For analysing the effects on GHG the Digital industry sector is divided into the three main sub-sectors:

-end user devices

-networks (including both mobile and fixed)

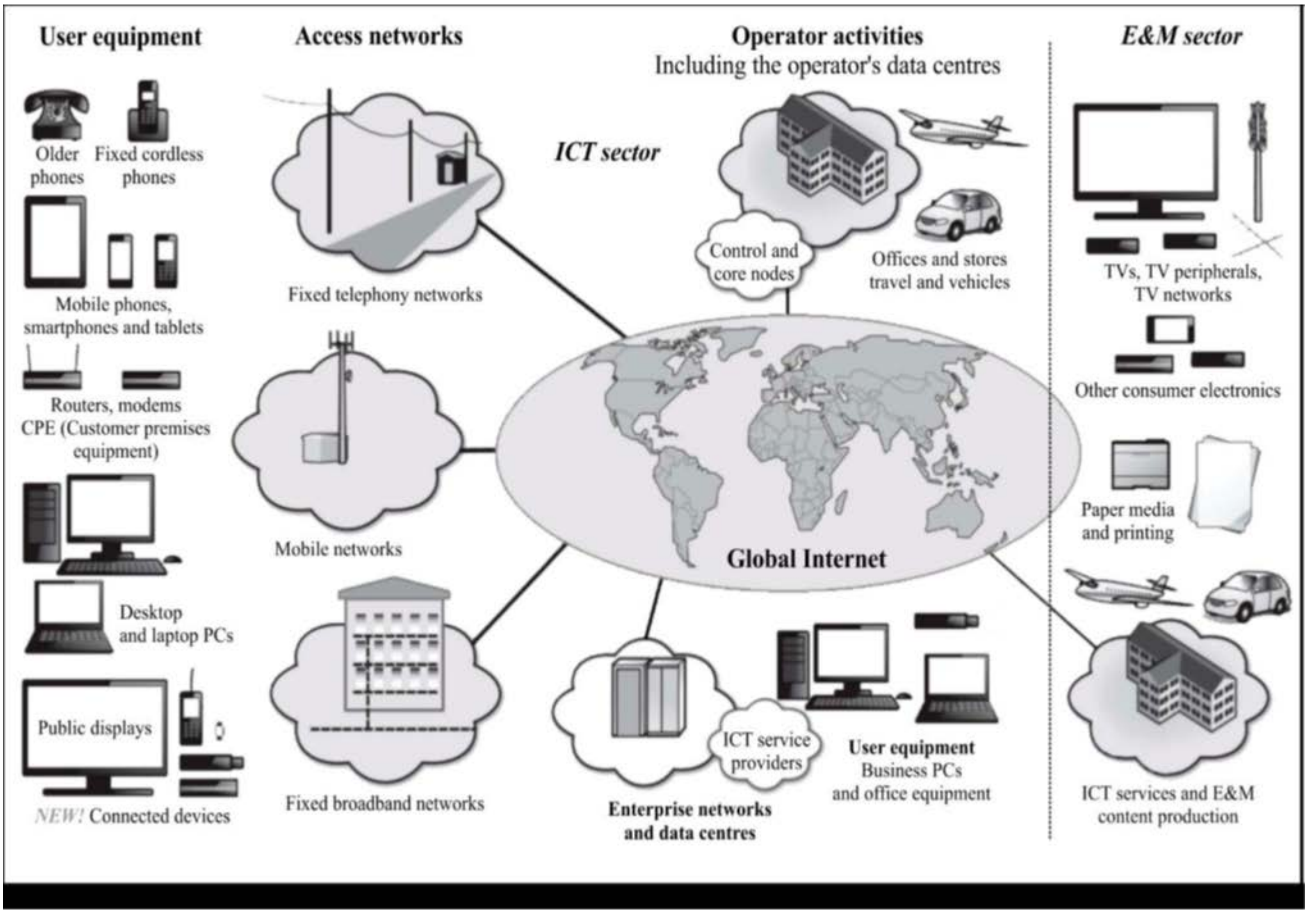
-data centres, including enterprise networks.

The GHG emissions in the usage phase and the GHG emissions in the manufacture and transport of the devices and infrastructure should be calculated. A large number of ICT devices are considered: cell phones, smartphones, landline phones, tablets, routers, modems, desktop computers, laptops, public displays and other devices connected to the Internet. In the E&M sector, television sets, television set peripherals, television networks, other entertainment electronics (games) as well as paper and printers are considered.

The ICT industry is composed mainly of two categories of electronic equipment namely:

(i) the electronic devices, such as PC's including desktops and laptops, along with the associated CRT and LCD displays, and handheld devices such as tablets and Smart phones, and

(ii) the infrastructural facilities such as data centres, comprising servers, networking gear, power and cooling equipment and communication networks, comprising customer premises access equipment, office networks, and telecom operator networks (including cooling and power provisioning overhead). Excluded are all E&M devices (TV's, set-top boxes, etc.).



Europe needs to estimate the following quantities for each of the components comprising the ICT industry:

-Production Energy which includes the material extraction and the manufacturing energy;

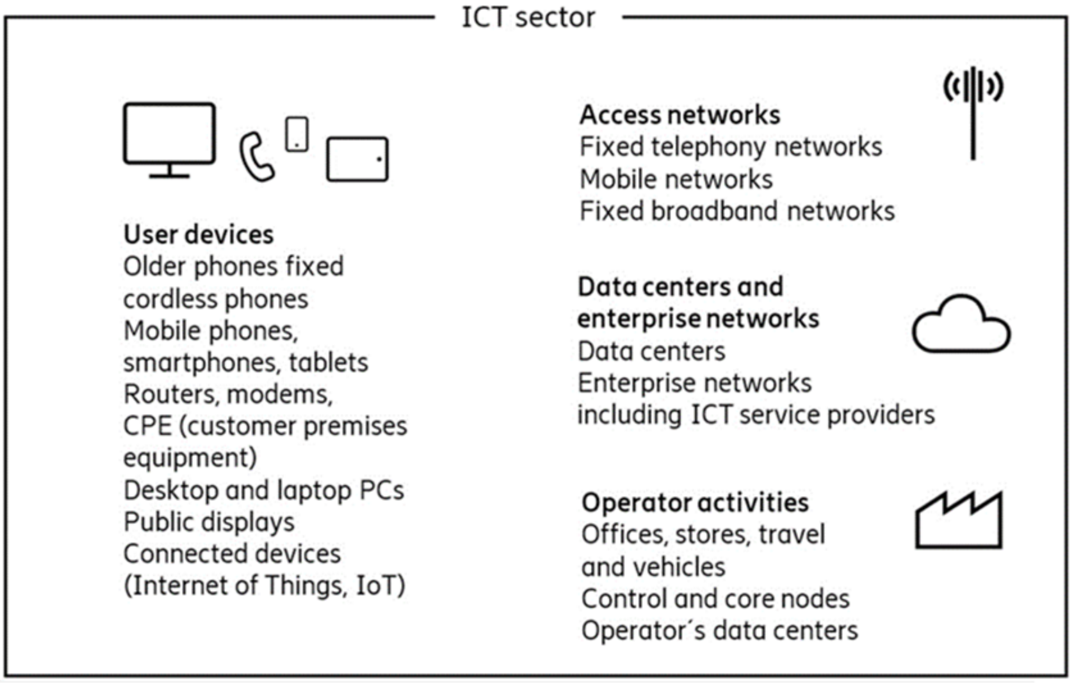
-Energy mix in each country or region

-Useful Life of the component, including any secondary use, before it is totally dismissed;

-Use Phase Energy which is the average annual energy consumption from operation;

-Active installed base.

Direct energy consumption refers to energy used during the operation, manufacture, and disposal of ICT equipment. The direct impacts include the energy used in the manufacture, operation and disposal of ICTs, along with the energy used for the associated data transmission network and the variety of dispositives. In short: Data Centres, Netwoks and User devices (See figure).


ICT sector
User devices
Older phones fixed
cordless phones
Mobile phones,
smartphones, tablets
Routers, modems,
CPE (customer premises
equipment)
Desktop and laptop PCs
Public displays
Connected devices
(Internet of Things, IoT)
Access networks
Fixed telephony networks
Mobile networks
Fixed broadband networks
Data centers and
enterprise networks
Data centers
Enterprise networks
including ICT service providers
Operator activities
Offices, stores, travel
and vehicles
Control and core nodes
Operator´s data centers

2 Technology and electrical mix

Emissions from electricity generation vary by type of fuel/energy source and by type and efficiency of electric power plants. The amount of CO_2 produced per kWh during any period of time will vary according to the sources of electricity supplied to the electric power grid during that time. Therefore, electricity-related CO_2 emissions and CO_2 emission factors will vary hourly, daily, monthly, and annually. Most European governments have CO_2 emissions estimates related to electricity generation on a monthly and annual basis. It will always depend on how you are generating that electricity. The electric mix of the country will guide you towards the factor you need. For instance, the Spanish Environmental Ministry publishes every year a study on the subject, providing a conversion factor for the emissions on final electric consumption. For example in 2013 it was 0,29 Kt CO_2/GWh. Obviously the differences are very important between the different countries of the EU.

Using as a simple measure of the environmental effect of ICT the electricity consumption, as the Taxonomy points out, without their conversion in terms of CO_2, which differs significantly between the different EU countries, it is a little error. When considering CO_2 emissions created by computing, the locally used grid mix is a key data.

Due to the difficulty of finding an adequate conversion factor, the energy consumed by the ICT sector is not an unequivocal parameter on the CO_2 emissions that are produced. However it is important to have figures on it. In the studies that try to estimate these emissions for the entire planet, a single conversion factor tends to be used, which is increasingly remote from reality due to changes in the electricity mix. However, the electrical evaluation is important. The Taxonomy proposes tasks exclusively for Data Centres and only advises that in the future it be done for Networks (it also indicates, consider the Software, but this is a factor with much less entity when referring to energy effects) however forgets the important effects of devices in the digital industry. Reviewing the literature on current results (both global and those corresponding to Europe) regarding energy consumption has been a complicated task, which explains the decision to include it in the **Annex**.

The technological developments that have occurred in recent years, together with those expected in the near future, are very different among the three components that interest us Data Centres, Networks and User devices, so it is necessary to treat them separately. A first conclusion of the Annex that inter is the enormous ambiguity surrounding the forecasts made by different authors and organizations:

"Assuming that in 2030 the energy demand of data centres and network infrastructures will be caused almost exclusively by cloud services; the energy demand of cloud **computing infrastructures can be estimated at between approx. 1,000 TWh/a and 7,500 TWh/a**. Depending on the energy-efficiency achieved, the energy requirements of cloud computing infrastructures could thus range from 2.5% to 19% of the global electricity requirements"

2.1 Electricity consumption of the ICT sector in Europe

In contrast to the global situation, the studies on the energy consumption of **data centres** in Europe are much closer together. The preliminary Ecodesign study on enterprise servers and data devices identifies an energy consumption of 78 MWh for data centres in Europe by 2015. In a study on the practical application of the new framework methodology for measuring the environmental impact of ICT, calculate an energy consumption in the EU27 of 52 billion kWh for 2011 and forecast an increase to 70 MWh by 2020.

In 2018, was estimated the development of the energy demand of networks in Western Europe. According to this estimate, energy consumption rose by a good 30% from 56 billion kWh in 2010 to 73 billion kWh in 2017. From today's perspective, it can be assumed that the current energy consumption of telecommunications networks in the EU28 is between 60 and 80 TWh / a. This is comparable to the energy consumption of data canters.

The energy consumption of data centres in the EU28 increased from 53.9 TWh /a to 76.8 TWh/ a between 2010 and 2018. This means that in 2018, accounted for 2.7% of the electricity demand in the EU28. Ongoing digitalization and especially the increasing availability of cloud services are leading to significant growth in data centre capacities. This growth is so strong that it has more than offset the significant efficiency gains achieved at all levels (hardware, software, data centre infrastructure), but the total energy consumption of data centresin Europe has risen.

Compared to 2018, the energy consumption of data centre is expected to increase by 21% to 92.6 TWh /a by 2025. While the share of cloud data centres accounted for 10% of data centre energy consumption in 2010, it increased to 35% in 2018. Unfortunately the estimations published by the "European Framework Initiative for Energy & Environmental Efficiency in the ICT Sector" saying that ICT currently accounts for 8-10% of the European electricity consumption are not well supported.

2.2 Data centres is only a part of GHG emission caused by ICT.

Let's start by recalling another three conclusions from the Annex, related to the estimations at the worldwide level:

A) It can be stated that there are no uniform opinions and no reliable calculation results on the energy requirements and GHG emissions of the data centres. However a moderate increase in GHG emissions over the past 10 must be considered likely. Despite all the existing uncertainty, a magnitude of the global GHG emissions from the data centres in 2020, is in the range of 200 to 250 Mt CO_2e (including production) is considered plausible.

B) Telecommunication's networks are between 140 and 300 Mt CO_2e. As with data centres, it is assumed that the energy demand in the usage phase is responsible for around 90 percent of total GHG emissions.

C) The global GHG emissions from ICT and consumer electronics devices are around 900 to 1,100 Mt CO_2e and it appears plausible. Without consumer electronics, is believed that the GHG emissions are around 500 to 600 Mt CO_2e.

Detailed and rigorous analysis of the ICT global carbon footprint, including both the production and the operational energy of ICT devices, as well as the operational energy for the supporting ICT infrastructure founded that, if unchecked, ICT GHGE relative contribution could grow from roughly **1–1.6% in 2007 to exceed 14% of the 2016-level worldwide. ¡** GHG by 2040, accounting for more than half of the current relative contribution of the whole transportation sector!. By 2020, the footprint of smart phones alone would surpass the individual contribution of desktops, laptops and displays. The GHG emissions caused by the manufacture, operation and disposal of digital devices and infrastructures are between 1.8 and 3.2 percent of global GHG emissions today. These are mainly caused by the large number of end devices used, with the manufacture of the devices making up an increasing proportion.

In summary, the approximate million tonnes CO2 from ICT sectors use in Year 2020 are:

-Data Centres use 160±25

-Mobile networks use 54±13

-Optical networks use 83±20

- Devices use 460±110

ICT is likely to contribute 1.8 to 3.2 percent of global GHG emissions by 2020. Adding:

Manufacturing processes 1000±60

We obtain:

Totals: 1.76±0.17 (2020)

In spite of the range of possible future developments of the energy consumption of data centres in Europe will be wide. It can be assumed that the digitisation of the economy and society as a whole will lead to a further increase in the energy consumption of data centres. In the trend case, data centres in Europe will consume 98.5 TWh / a in 2030, the relative weight of Data Centres in these figures raises doubts about the unique selection of these facilities in Task 7.1.

3.- European Regional inequalities in Data Centre Installations.

There is a clear trend towards operating servers in very large hyperscale data centres in the future. The trend towards large cloud data centres is also reflected in the regional distribution of data centre energy consumption. International hyperscale cloud providers often build their large data centres in Norther Europe. The reasons for this decision include low costs for cooling, low electricity prices and the availability of renewable electricity. This development has increased the energy consumption of data centres in Europe, especially in Northern Europe. In the coming years, this trend is likely to become even more significant. The share of data centre capacity in Southern and Eastern Europe is relatively small and the corresponding share of these regions the energy consumption of data centres is low.

The majority of data centre capacity is located in Northern and Western Europe. These regions were responsible for 82 % of the energy consumption of data centres in 2018. By the year 2025 this proportion will rise to 87%. Especially for the energy consumption of data centres in Northern Europe a strong increase of 48% from 26.3 to 38.9 TWh/a is predicted for the period 2018 to 2025.

Due to big GAFAM installations, two small countries, Denmark and Ireland, are expanding data centre markets and quickly becoming a major source of electricity demand. In Ireland, projections by transmission system operator show that electricity demand from data centres and other large energy users could more than double in a decade to account for almost 30% of the country's electricity demand in 2028. In Denmark, data centre electricity consumption is projected to grow from less than 1% today to 15% of total electricity consumption in 2030. However, these projections still have considerable uncertainty, given the potential for new project announcements as well as cancellations.

Hyperscale data centres are often in regions with abundant access to renewable energy, such as Google's Finland data centre. However, these locations tend to be away from population centres which means higher network response times as data must travel further to the end-user. As urbanization increases, the need for low latency will require data centres to be sited closer to the user but these locations may be less suitable for access to renewable sources of electricity or natural water sources for cooling.

4. Taxonomy of ICT energy effects (See Figure)

Direct energy consumption refers to energy used during the operation, manufacture, and disposal of ICT equipment. While this definition reflects common usage in the ICT energy literature, we note that it may contrast usage elsewhere—for instance, in economic input-output analysis—where direct energy use may be synonymous with operational energy consumption, and manufacturing and disposal energy are sometimes described as indirect effects. Final energy consumption covers the energy consumption of end-users, such as industry, transport, households, services and agriculture. It excludes consumption of the energy sector itself and losses occurring during transformation and distribution of energy (e.g. power plants, district heating plants, oil refineries, coke ovens and blast furnaces). It is also excluding all non-energy use of energy carriers (e.g. natural gas used for producing chemicals, oil based lubricants, bitumen used for road surface). Quantities delivered to international aviation and international marine bunkers are also excluded from the final energy consumption. Energy consumption during other parts of the ICT equipment lifecycle—i.e., manufacture and disposal—is often called embodied energy and can be a nontrivial component of ICT equipment's direct energy use. The relative significance of embodied energy to operational energy varies by component and by scope of analysis. At an even broader level, the embodied energy of the entire Internet infrastructure is roughly equivalent to its operational energy consumption over its lifetime, which is partly due to the fact that network cabling has high embodied energy but no operational energy use.

ICT adoption leads to efficiency in and substitution for conventional products and services. Efficiency improvement occurs when, for example, smart building technology reduces air conditioning energy consumption by tailoring climate-control to the real-time needs of building occupants. An example of substitution is the replacement of air travel with teleconferencing. There is no guarantee, however, that the substituted ICT service will be less energy intensive than the conventional service it replaces, and even evaluation of simple cases is not always straightforward. An electronic billboard, for instance, may use more energy than a static, printed billboard, since it uses electricity to display the image. This energy consumption can be compared to the energy required to print the same image. However, the electronic version also avoids energy associated with changing the billboard—i.e., sending a worker out to make the switch. An additional complication is that the services are not strict functional equivalents: the electronic version allows animated displays, which may lead to higher success rates and profits—perhaps making energy consumption per successful 'target' lower even as per-billboard consumption is higher.

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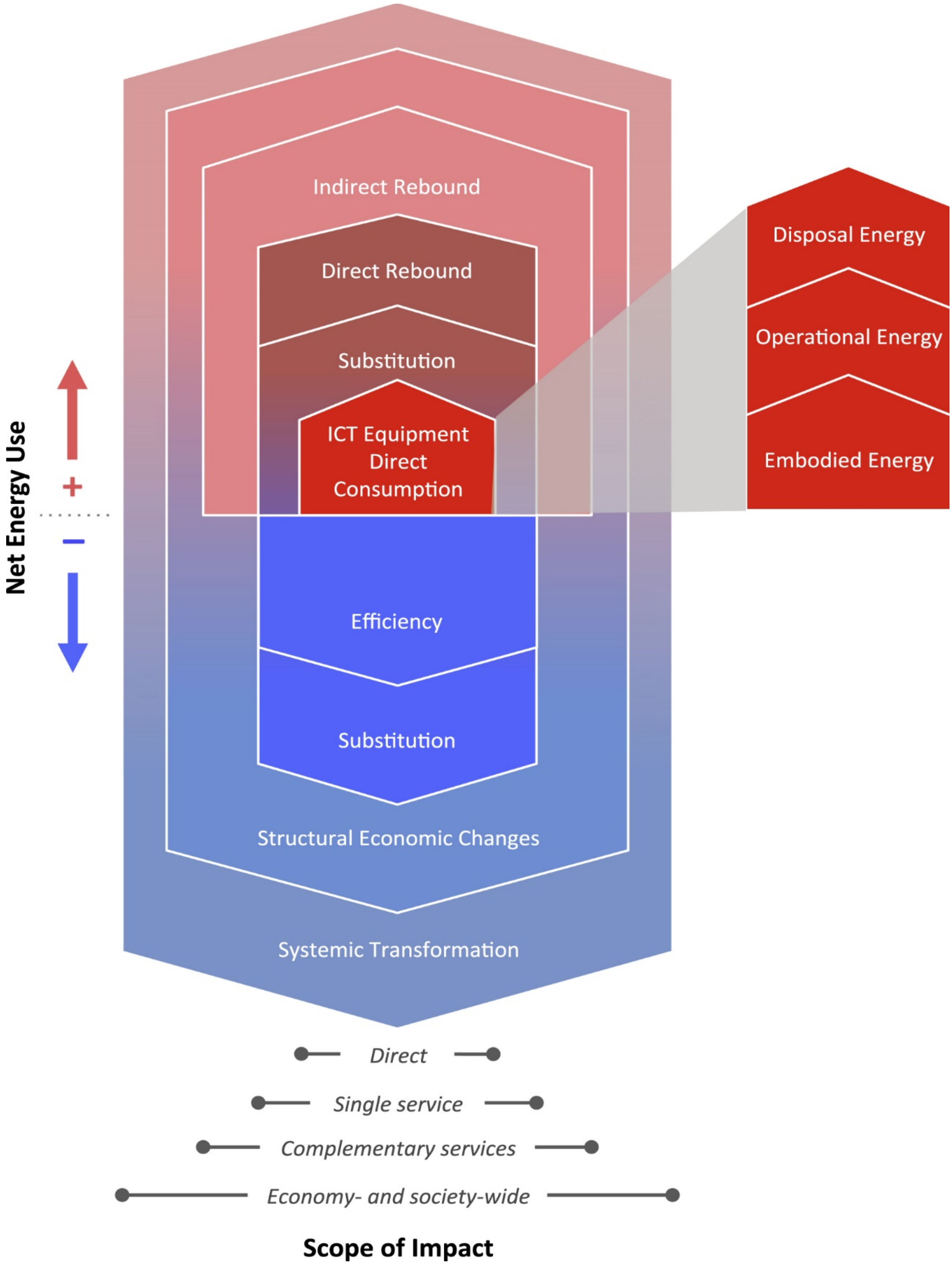


Any energy reduction achieved through efficiency or substitution can be plagued by rebound effects, in which expected gains are offset by induced additional consumption. Rebound is typically broken into direct rebound, indirect rebound, and economy-wide effects. Direct rebound effects are energy service own-price-elasticity effects: as prices fall (due to improvements in efficiency or productivity), substitution and income effects increase consumption. For an ICT example, if an e-book is less costly than a conventional book, then consumers might purchase more books. Direct rebound is constrained by saturation: there is a limit to the number of books people will buy, no matter how cheap they become. Alternatively, these savings could be spent on other goods and services, which are indirect rebound effects. Indirect rebound effects result from cross-price elasticity of demand for other products and services due to increased real consumer income.

Service-specific studies like those discussed above can highlight individual pathways for ICT to alter energy consumption, but they rarely address the higher-order effects beyond efficiency and substitution. These rebound and systemic effects are crucial to an integrated picture of whether—or under which conditions—ICT services lead to in a net increase or decrease in system-wide societal energy use. If obtaining conclusive results for a particular service can be complex and uncertain, the macro picture is even more so. The inability to draw concrete conclusions reflects, in large part, uncertainty regarding the rebound effect for ICT and the inability to disentangle root causes of interrelated economic effects. The dynamics of these effects are hugely dependent upon human behaviour, which is laden with uncertainty and

Economy-wide effects occur when the ICT introduction causes macroeconomic adjustments across economic sectors. That is, the ICT industry can promote or inhibit growth in other sectors of the economy, inducing structural changes that have energy use implications of their own. For example, e-commerce is having broad effects on the logistics industry including growth in urban freight vehicle sales and changing patterns in distribution centre floor space increased trucking and adoption of new pricing strategies by freight carriers and use of more specialized packaging and a broader range of box sizes.

Finally, transformational effects refer to the altering of human preferences and economic and social institutions caused in part by the development of ICT 002). Historical examples include the advent of the telephone and automobile, which heavily altered where and how people lived and worked. We might conceive of a similar transformation (one of many possible ICT-enhanced futures) in which the fundamental constraints on where people live and work continue to loosen: e-commerce and home delivery make proximity to traditional retail outlets less important, seamless telework results in less commuting, and driverless vehicles allow for more productive use of the commuting time.

4.1 Virtualization and Optimisation

ICT energy effects can be broadly grouped into first-order impacts due to direct consumption, second-order effects resulting from process changes, such as efficiency, and third-order effects due behavioural and economic changes, a fourth level, essentially breaking third-order effects into rebound effects and broader systemic change.

The ICT indirect effects may be categorised into five categories: optimization, substitution, induction, supplementation, and creation. The first two map directly to efficiency and substitution, while induction, supplementation, and creation align loosely with (or, perhaps more strictly, are special cases of) direct, indirect, and economy-wide rebound effects, respectively.

CTs provide a multitude of services, but these may be grouped into two broad categories:

Virtualisation: where ICTs provide a complete or partial substitute for previously existing goods (e.g. books, music, videos) or services (e.g. healthcare), or provide entirely new goods or services (e.g. online video games, or 'e-games') .

Optimisation: where ICTs improve the design or operation of various technologies, systems and processes (e.g. buildings, logistics, industrial processes).

These two categories may be may subdivided into several application domains. Virtualisation into three application domains, namely:

e-services,

e-materialisation, and

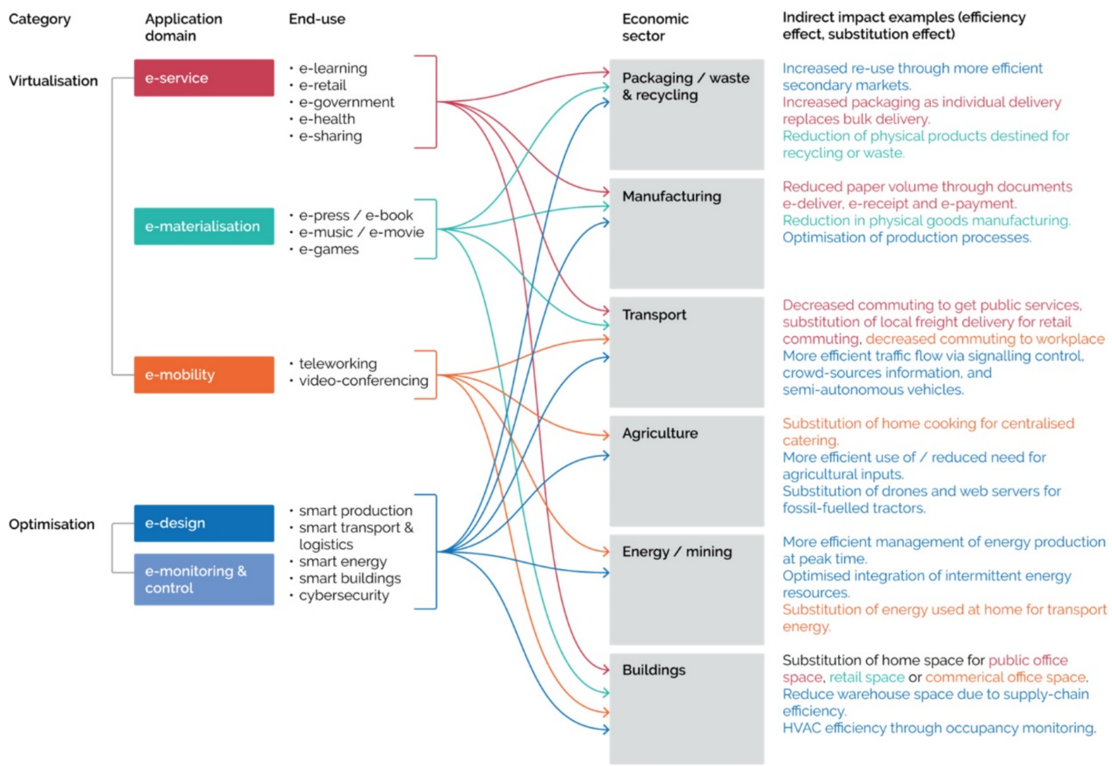
e-mobility ;

Optimisation into two application domains:

e-design, and

e-monitoring and control.

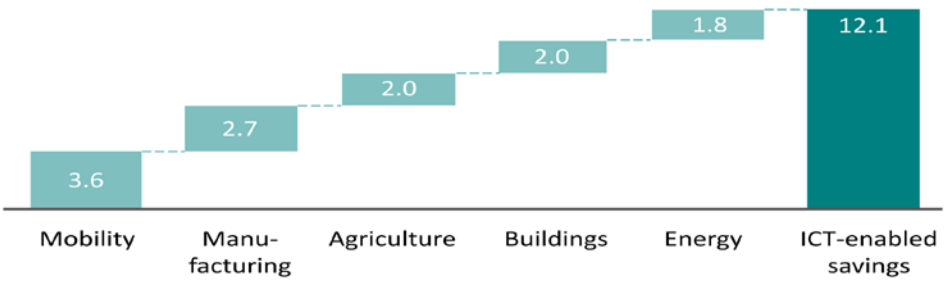
Each application domain encompasses a variety of different services and technologies. For example, e-materialisation includes print versus electronic newspapers (e-news), traditional versus electronic books (e-books) and DVDs versus streaming video (e-video) amongst others. Similarly, 'e-monitoring and control' includes electronic control of industrial processes, and electronic control of heating, ventilation and air-conditioning in buildings amongst others. There are also overlaps and interdependencies between different services and domains: for example, e-books are dependent upon e-payment mechanisms, such as electronic bank transfers. Each of these different services may, in turn, have higher order impacts on energy consumption in several different economic sectors—such as transport, buildings and agricultura Figure summarizes this proposed classification scheme and provides some illustrative examples.



4.2 The industrial sectors present in the Taxonomy.

In the Figure are represented the six economic sectors correspond to the areas indicated in the EU Taxonomy: Agriculture and Forestry; Manufacturing; Electricity, gas, steam and air conditioning supply; Water, sewerage, waste and remediation; Transportation and storage and Construction and real estate activities.

Smart ICT solutions can save eight to ten times more greenhouse gases than caused by the entire ICT itself. Cloud services can support many of these ICT-related savings potentials. The Figure shows the CO2e abatement potential by each sector. Figure provides an overview of the CO2 saving potentials in the various economic sectors



On light of the concerted efforts to reduce global greenhouse gas emissions (GHGE) per the so-called Paris Agreement, ICT has received little attention as a significant contributor to GHG and if anything is often highly praised for enabling efficiencies that help reduce other industry sectors footprint. In terms of the recommendation of the TEG to de Commission:

"Context-specific digitalisation solutions for resource efficiency, defined as development and/or use of integrated systems i.e. combination of software and hardware, or software applications that minimize resource consumption in other sectors of the economy, these digitilasion solution are essential to ensure that other sectors of the economy – agriculture, energy, transport, buildings – meet the eligibility criteria set for other sectors' inclusion in the EU Taxonomy.

Examples include:

• Transport: Electric-vehicle smart charging - manage EV charging stations smartly to leverage on the extra storage capacity connected to the grid.

• Agriculture: Precision agriculture digital solutions – allow, for example, for the right amount of water for irrigation, or fertiliser use.

• Energy: Innovative grid equipment (e.g. short circuit breakers) to ensure security in grids with growing decentralised renewable production.

Data can lead to a more efficient use of energy and can contribute to mitigating climate change effects through: - improving the efficiency of farming methods and increasing yields; - more effective monitoring and management of electricity use, heating and cooling; - enabling a more efficient distributed system of low carbon energy generation and smart grids; - using smart devices or digital services that enable individuals to have lower carbon lifestyles; - improving logistics, vehicle use, vehicle efficiency and use of public transportation; - enabling more effective remote working or education, thus avoiding travel and commuting; - and even through the replacement of physical products by digital services"

It is a bit contradictory that the Taxonomy puts in the Information and Communication area, tasks that correspond to the aforementioned, which produces a misleading situation, when ICTs have

4.3 Energy needs demanded for economic sectors in a digitalised world not considered within the Taxonomy.

With their corresponding energy demands, the importance of ICT, outside of the aforementioned economic sectors, is increasingly important, whether certain digital technologies can be fully deployed depends on different factors. Economic aspects such as market demand, costs, and the speed of innovation will be decisive for certain technologies and whether they are taken up. Similarly, IT related aspects such as data security, data privacy, and operability.

New E&M developments

Media and entertainment are conducted via smart devices and broadband internet. As highlighted in the current scenario chapter, consumer applications are responsible for a consistent amount of worldwide data workloads and compute instances, accounting for about 25%.

TV/video and social networking are the two main app types and services that generate engagement and data traffic. The combination of apps for TV/video services and social networking accounts for more than half of the traffic, while gaming generates disproportionately low data traffic.

Key technological solutions such as open community platforms, gamification and virtual reality have the potential to create personalized ecosystems that will be increasingly affordable and engaging, and will rely more and more on large broadband connections such as the 5G, e.g. for streaming sophisticated media contents such as online games. For instance, in 2019 YouTube released Stadia, a cloud gaming on-demand service streamed through the cloud which can be used on any portable device. Among the different media and entertainment options, video streaming is by far the most environmentally unfriendly. A recent study showed that video **streaming is far from being green**: it accounted for 63% - 71% of global internet traffic in 2015, and it is projected to reach about 80% by 2020, leaving the remaining share to software downloads, audio, social networking and web browsing. Every second, nearly a million minutes of video content will cross the network by 2020. Also, social platforms such as Facebook and Twitter are providing real-time video streaming services, meaning data will grow even more in the near future in this sector.

Hence, the cloud market for media and entertainment will keep growing. Key areas for further developments in the media and entertainment industry will be online community platforms, video streaming, videoconferencing, augmented reality and virtual reality, and gaming. Those services that are particularly data and energy-intensive are the video streaming processes. Media and entertainment data growth is expected to exceed 6 zettabytes in 2025, compared to 1 zettabyte in 2019 and availability will also be a decisive factor for the uptake of certain technologies.

Healthcare

The healthcare sector is already experiencing a transformation into an information centred industry, with cloud computing playing a central role:

a) Smart devices such as wearable watches or mobile phone devices will constantly monitor health-related parameters, so that patients will be able to monitor, store, transmit and process data on their personal health situation and history through smartphone apps.

b) DNA sequencing (also known as genomics) is gaining momentum. Public archives for the raw sequencing data have double in size every 18 months, and the costs of DNA and pathogen sequencing are expected to drop significantly by 2030. This, combined with access to a large database securely storing the data, will enable doctors to use data analytics to arrive quickly at precise diagnoses and to tailor treatments accordingly.

c) Augmented reality, which provides assistance during surgery and can help improve medical training, might also become a trend in medical healthcare, e.g. to perform remote diagnostic and tele-surgery thanks to the reliability and accessibility of real-time data, which relies itself on the availability of strong networks, such as the 5G.

Data generation and big data analytics are the key technologies enabling automatic processing and the interpretation of large amounts of data. This process is already partially facilitated by open standards which enable collaboration (through workflows and information sharing) between hospitals, medical practices, insurance companies and research institutes. As a matter of fact, cloud computing provides the necessary system environment that makes it easy for healthcare organizations to provide easy Access to computing power with a lower initial investment than previously required for purchasing or long-term licensing. In addition, cloud environments are lowering the barriers for innovation and modernisation of IT systems and applications.

The demand for health care will continue to rise, mainly due to aging and the growth of the world population, but also due to the increasing interest of people in health care. In terms of data generation, the healthcare sector is predicted to grow fast, namely from 2 zettabytes in 2019 up to 10 zettabytes in 2025. Out of this, about 8.5 zettabytes will be stored, and about 6 zettabytes will be generated in real time. Nevertheless, some factors will be crucial in ensuring the broad diffusion of digital options across the healthcare sector, such as an increased investment in technologies, the relocation of established processes in healthcare via data integration and comparative analysis, and the development of skills combining medical knowledge and data analytics. Ensuring data privacy, data security and reliability are also two critical factors for the uptake of digital technologies in the healthcare sector.

Industry 4.0

The intense use of digital technologies within the industrial sector of the future is also known as Industry 4.0 or as the Industrial Internet of Things (IIOT). Smart sensors and devices connected to each other constitute the IoT, which i continuously generates data that is collected, processed and analysed in cloud environments, either at the edge or centralized in order to increase productivity and quality while reducing energy and other resource usages. Innovations like virtual manufacturing, customer centric production, 3D printing and virtual production networks are also new trends reshaping industrial production.

The key technologies which will enable Industry 4.0 are mostly the Industrial Internet of Things and Machine to Machine communication, which will strongly rely on edge computing, data analytics & cloud computing. Data generation in the industry sector is already the biggest of all sectors considered, accounting for about 5 zettabytes in 2019, which is expected to grow up to 23 zettabytes in 2025. Data for storage will grow from 3 zettabytes in 2019 up to 18 zettabytes in 2025. Noteworthy is the amount of generated real-time data. Companies are increasing the capture and use of real-time data to include data from IoT and actual product use, tracking everything from engine location to performance. Predictive maintenance and asset performance management are becoming massive data generation engines that are driving the adoption of data management and analytics strategies focused on operational excellence. As a result, real-time data will grow from about 1 zettabyte in 2019 to 10 zettabytes in 2019.

Since no industry is fully optimised, even in its advanced state, there is room for improvement. This is especially true for investment in Blockchain and artificial intelligence. A timeline of 5 to 10 years for Industry 4.0 to become fully integrated across operations and industries has been estimated.

High performance Computers

A supercomputer is a computer with a high level of performance as compared to a general-purpose computer, these systems play an important role in the field of computational science, and are used for a wide range of computationally intensive tasks in various fields, including quantum mechanics, weather forecasting, climate research, oil and gas exploration, molecular modelling (computing the structures and properties of chemical compounds, biological macromolecules, polymers, and crystals), and physical simulations (such as simulations of the early moments of the universe, airplane and spacecraft aerodynamics, the detonation of nuclear weapons, and nuclear fusion). They have been essential in the field of cryptanalysis.

The packing of thousands of processors together inevitably generates significant amounts of heat density that need to be dealt with. Each supercomputer is a project per se. An auto manufacturer might build a more fuel-efficient engine, but if a motorist leaves the vehicle idling all day, these hard-won efficiency gains are undermined — the same holds in HPC. How data centre resources are used and managed is a critical part of the problem. Many existing supercomputers have more infrastructure capacity than the actual peak demand of the machine – designers generally conservatively design the power and cooling infrastructure to handle more than the theoretical peak electrical power consumed by the supercomputer.

Designs for future supercomputers are power-limited – the thermal design power of the supercomputer as a whole, the amount that the power and cooling infrastructure can handle, is somewhat more than the expected normal power consumption, but less than the theoretical peak power consumption of the electronic hardware. Throughout the decades, the management of heat density has remained a key issue for most centralized supercomputers. The large amount of heat generated by a system may also have other effects, e.g. reducing the lifetime of other system components. Reducing HPC carbon footprint is a multi-dimensional challenge. More efficient designs, more power-efficient components, and better management are all parts of the puzzle. Operating systems were developed for existing hardware to conserve energy whenever possible. CPU cores not in use during the execution of a parallelised application were put into low-power states, producing energy savings for some supercomputing applications. Fortunately, technologies available today ensure that HPC performance and environmental responsibility don't have to be mutually exclusive.

Housing

The house of the future will be smart. Automation systems and sensors will be integrated into smart grids via smart meters, which can perform energy use analytics, forecasting and optimisation. Sensors will allow continuous monitoring of temperature, lighting and other parameters in real-time. Data collected via smart meters and other smart home solutions are controlled via smart devices, allowing users to monitor energy use and control building functions via remote technology. This transformation is already happening: the number of household appliances that are connected to communication networks, ranging from televisions and washing machines to doorbells and security cameras, has seen a sharp rise in recent years.

A combination of smart devices, Internet of Things and data analytic tools, e.g. for predictive maintenance, will make smart housing possible, as well as machine automation and pattern recognition, e.g. by employing Artificial Intelligence algorithms. Estimations of future data generation on smart homes are difficult to find in the literature, although it suggests that the amount of data will grow considerably. Some questions, which still need to be fully addressed, will shape the effects of smart homes on cloud energy consumption. At first, there is the question of which data are to be stored and where, e.g. for data analytics purposes. A computing task can be either executed on the IoT and smart home devices or outsourced to the cloud. Where to compute depends on overhead trade-offs, data availability, data dependency, the amount of data transportation, communications dependency and security. Data generation will also vary among different smart devices: sending 10 to 15 queries to a virtual assistant each day would require about 30MB a month, whereas a security camera average of 60 GB of data per month at the mid-range setting, rocketing to 140 GB for high resolution. With a subscription to Nest Aware – the paid cloud service that saves Nest Cam's video stream into history files, the average use will be 120 GB of data a month at that same mid-range setting and up to 400 GB per month for high resolution and advance features, e.g. if facial recognition is activated. Another difficult point to predict is how many devices a smart home will have on average.

Recent studies have evidenced that in the US (to be confirmed in EU) in each house at least one connected device is present, with 26% owning more than three. Typologies of devices range from smart appliances (Smart TV, washing machine etc.), to devices for utility management (smart thermostat, light regulators, etc.), to home entertaining and security (such as video-streaming devices). Recently, in Austria a smart building was constructed employing about 800 sensors such as smart LED sensors for light regulation, which should also lead to energy savings . Hence, the adoption of smart devices in each home can vary significantly. In the future, the most influential factor will be the amount of new smart homes that will be built and equipped with such a high number of sensors and devices. However, it is predicted that by 2040, 50% of the household electricity demand for appliances will come from connected devices.

Finance & E-Banking

The financial and e-banking sectors are already in the process of being shaped by digital technologies. Through e-banking, banking products and services are delivered through electronic channels like the internet or mobile banking to millions of additional people, who are now able to operate in the financial system and to perform complex banking operations from everywhere. Electronic payment systems will eventually make cash redundant. In retail, more transactions are now carried out online and retail e-commerce sales worldwide reached $1.2 trillion in 2013, which equals a growth rate of nearly 20%, with the majority of growth coming from emerging markets. Finally, cryptocurrencies such as Bitcoin and Ethereum saw a tremendous uptake in the past 10 years.

The digital technologies which will enable e-banking and e-commerce will mostly be online platforms, where data security and data protection are decisive factors. The adoption of cryptocurrencies based on Blockchain technologies also seems to be a field that interests many banks.

Data generation in the financial services is expected to exceed 10 zettabytes by 2025, out of which 9 will need to be secured and 3.5 zettabytes are real-time data.

Smart transport

The digitalisation of transport will improve system operations, safety, efficiency and service, as well as lower the costs. The control and optimisation of traffic are facilitated through connected smart sensors, location-based applications and intelligent infrastructure, all working together to make traffic, driving and parking more efficient. Through connected private transportation people and vehicles having similar origins or destinations are connected. For example, smartphone enabled carsharing or car-pool platforms can help travellers meet at designated spots to travel together.

Smart logistics will connect vehicles, products and load units, thereby improving route and load optimisation and reducing the amount of waste in the system. A technology that seems promising, although it is still in its experimental phase, is autonomous driving.

Smart transport will take huge advantages from the deployment of sensors for data collection, communications technologies to enable remote control, and advanced data analytics to calculate the most efficient paths in real time. Autonomous driving, on the other hand, will strongly rely on real-time information gathering and data analytics, as well as on the 5G network infrastructure.

Increased connectivity of new mobility sharing services combined with advances in vehicle automation and electrification could result in substantial but uncertain energy and emissions impacts. Over the longer term, road transport energy use could either drop by about half or more than double, depending on the interplay between technology, policy and behaviour.

As transport becomes increasingly digitalized, questions about vehicle and software certification, liability, cybersecurity, data privacy, and employment will also play an important role in the uptake of digital technologies in the transport sector.

4.4 Energy needs in the Technology trends

Digitalisation is described as a new megatrend that will make use of disruptive technologies to transform the way most economic sectors are traditionally conceived. Nevertheless, for all key digital technologies, data is at the heart of digital transformation. The demand for cloud services will happen in response to a growing demand for data storage, management and transmission. The key digital technologies considered are namely: Smart sensors and the IoT, Big Data Analysis, Blockchain, 5G & satellites and Artificial Intelligence, Deep Learning

Nonetheless, not all key digital technologies are at the same stage of development. According to existing studies the IoT, Big Data and Machine Learning are already at a mature stage, which could reach a scale–up stage in the next few years, and might deserve special attention as they are the most impactful technologies. Blockchain is still at the stage of being improved, as it is currently massively employed for cryptocurrencies, but still immature for applications in other fields, for its energy demands. Deep Learning is still in the early stages of its development as an emerging technology, although the pace of its development is fas**t.**

Smart sensors and the IoT

Smart sensors and devices connected to the cloud to store, share and analyse data for monitoring and optimisation purposes – the so–called Internet of Things, will be a predominant trend in the future and especially in the manufacturing, housing, transport and healthcare sectors. Over the longer term, it is conceivable that most electrical devices – and even some consumer items such as clothing – could become connected IoT devices, using energy to collect, process, store, transmit and receive data. The number of connected IoT devices is expected to increase from about 6 billion in 2016 to 20 – 30 billion by 2020. As already highlighted, the devices will need mains electricity and tap into the energy used by data centres and network services. Different studies estimate that gains in energy-efficiency could keep energy demand growth largely in check for data centres and networks over the next five years. In the longer term for instance, industry estimates suggest that by 2030 smarter systems could save 10 times the carbon emissions they generate.

The energy consumption due to data generation, analysis and transmission of Smart sensors and the IoT alone is already remarkable. According to estimates, 2.5 to 5 quintillion bytes of data are already produced every day, and data traffic and energy consumption due to the IoT is predicted to skyrocket in the next years, and produce 3.5% of the global emissions by 2025 and 14% by 2040.

Anyway, the energy demand varies according to the typology of smart devices and sensors. Mini devices that require little interaction will produce minimal data and cause very low bandwidth costs. Remote devices to turn on and off appliances such as light bulbs or a thermostat are very simplistic. Devices that will need to send data to and from the internet regularly as well as monitoring devices (such as health smart devices or GPS tracking devices), or devices that are never turned off, will have a medium usage and electricity consumption. As soon as an IoT device begins sending or receiving data that is not simply text or numbers, higher bandwidth usage is needed. This is especially true for video data: global computing power demand from internet-connected devices including high resolution video streaming, surveillance cameras and a new generation of smart TVs, was consuming roughly 3-5% of the world's electricity in 2015 and is increasing at a rate of 20% each year.

Extreme bandwidth usage will occur due to IoT devices which are not typically available yet for standard residential use by the average citizen, but could soon be widely applied. These are generally more complex devices that track a huge amount of data and transmit it to the cloud in real-time, as will occur with connected cars, which are expected to generate data traffic to the cloud up to 25GB per driving hour.

Concerning mains electricity consumption of connected devices, standby power consumption is a particular concern. Inefficient networked standby could waste around 740 TWh per year by 2025, equivalent to the current annual electricity consumption of France and the United Kingdom combined. The standby power consumption of IoT devices that are plugged in (excluding televisions and computers) is projected to grow to 46 TWh by 2025, with 36 TWh coming from home automation (IEA, 2014). Nevertheless, economies of scale and product improvement are expected to halve the energy intensity of active control devices over the next 25 years, from an average of around 2 kWh per square metre (m2) per year in 2010 to 1 kWh/m2 /year in 2040. Globally, active control devices are projected to consume 275 TWh in 2040. That is to say, direct energy use in the long run will continue to be a battle between data demand growth versus the continuation of efficiency improvements of smart devices and sensors.

Advanced data analytics

Big data analytics is the use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes. Big data comes from sensors, devices, video/audio, networks, log files, transactional applications, web, and social media much of it generated in real time and on a very large scale. Artificial intelligence (AI), mobile, social and the Internet of Things (IoT) are driving data complexity through new forms and sources of data.

Big data analysis finds and will find its application in many economic sectors, since it makes use of the information generated by smart sensors and the IoT, allows DNA sequencing, Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market makes it possible to optimise the performance of smart appliances and smart homes, and so forth. In general, big data analysis can be used for descriptive analysis (to tell what happens in a certain system), predictive analysis (to tell what might happen in a certain system), or prescriptive analysis (to tell what is desired to happen in a certain system, such as when one defines a certain objective).

The employment of big data analytics is already huge and will be massive in the upcoming years, to the point that the issue is described as a "tsunami of data". It is estimated that out of the 2.5 – 5 quintillion bytes of data the world produces every day, 90% of this is unstructured. The massive amount of data needs to be analysed in an iterative, as well as in a time sensitive manner, with the availability of advanced Big Data analysing technologies.

Other than assuming that it will be considerable, it is difficult to predict how much energy will be required to compute this amount of data. This will depend on the amount and typology of data generated, on the path and speed of data transmission, on the efficiency of the analytic tools employed for the analysis as well on the abilities of the physical compute infrastructure.

Blockchain

Blockchain made its first appearance in 2008 as a technology for the development of cryptocurrencies. A Blockchain is a growing list of records, called blocks, which are linked using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data. Thanks to this protocol, Blockchain allows parties to co-create a permanent, unchangeable and transparent record of exchange and processing, without having to rely on a central authority (central ledger). Simply put, a Blockchain is about the exchange of value and how to make it instant and trustworthy.

This trust enables distributed account management, which is a great advantage for the use of cryptocurrencies. For current cryptocurrencies, the transparent record of the Exchange and processing of Blockchain is ensured through the validation of transactions via the resolution of an encrypted algorithm. In exchange, those validating the transaction receive a token (e.g. the Bitcoins, or other forms of credit). But the machines need huge amounts of energy for validating the transactions for current cryptocurrencies: it has been widely reported that the Bitcoin mining network now consumes more electricity than 159 countries of the world together. According to the Digiconomist Bitcoin Energy Consumption Index , it is estimated that the annual energy consumption of Bitcoin and Ethereum combined accounts for about 40 to 70 TWh, which is more than the annual energy consumption of an entire small country.

A crucial question is nevertheless if and how Blockchain technology can be applied in the future in a way which does not dramatically affect energy consumption, and in fields other than cryptocurrencies. Blockchains has the potential to improve traceability, reduce or totally eliminate the need for a trusted middleman in many operations, be it a supply of certified renewable electricity coming from distributed energy generation, the verification of legal provisions, the establishment of a patent, or a simple payment.

Rewards can be fungible (tradable for other cryptocurrencies) or non-fungible (identity based reputation tokens). Examples of such purpose-driven tokens include proof of CO2 emission reduction (i.e. Solar Coin, Electric Chain, Sun Exchange), proof of energy consumption reduction: Energy Mine, Electron), proof of trees planted, recycling, etc. (Plastic Bank, Earth Dollar, Bit Seeds, Eco Coin, Earth Token, Recycle To Coin). Although the technology is still in its early stages, with many technological, legal and network effect challenges ahead, the potentials for future developments are huge.

5G & Satellites

5G is the successor to 4G, and it is much more than just a new wireless standard. 5G is a key enabler for disruptive communication technologies. The extremely powerful mobile communication technology makes the promises of Industry 4.0 and autonomous driving possible. It will greatly simplify the dynamic design and operation of communication networks and the secure networking of things and people, and will contribute to all economic sectors. New business models will emerge in vertical markets.

The data packets sent via 5G not only have to be transferred quickly. They also have to be processed close to their origin. This requires computing capacity, storage space and intelligent algorithms that are integrated into the networks. This is why the researchers are expanding the 5G systems with cloud concepts. In the future data sent by sensors, components, robots or machines (for instance in the Smart Industry) can be processed in the cloud. If a company sets up its own local cloud and the servers are located on the premises, even very low latencies can be achieved. One advantage of this is that the computing capacities in the cloud are easily scalable. Edge computing also helps speed up traffic. Data is already being processed at new base stations or special gateways and data centres at the edge of the networks.

Communication service providers (CSPs) have therefore great expectations - both for the higher capacity and for the new services and innovations. 5G, in combination with the Internet of Things and Edge Computing, offers opportunities that were unimaginable a few years ago. 5G can be described as a convergence of underlying technologies that undergo multi-dimensional acceleration, including the unification of fixed and mobile networks, private and public (hybrid), communications provider, and edge cloud. Also, the 5G technology makes it possible to equip virtually every component with a sensor and an ID.

During production, the resulting products continuously collect data on their processing. These can then be stored as a kind of individual protocol for each component with all relevant production data. The innovative Massive MIMO (multiple-input multiple outputs) technology delivers increased ranges and energy-efficient, directional transmission. Especially at high frequencies in the millimetre-wave range, for example the recently defined 26 GHz band, these antennas feature a compact design and a high bundle gain. A prerequisite for the high data transmission rates is the extension of the frequency spectrum. While the previous 4G mobile (LTE) is used in the range between 700 megahertz (MHz) and 2.7 GHz, the spectrum in which 5G is operated is significantly larger.

In order to increase the reliability of data transmission, identical data packets are sent simultaneously via several base stations and in different directions, so that their arrival is guaranteed. This is known as redundancy, which obviously increases data traffic and hence the energy consumption of data transmission.

Satellites play an important role in the development of 5G. At 5G, satellite communications and terrestrial radio communications will converge. The definition of the 5G standard takes into account the technical characteristics of the satellites. The LEO (Low Earth Orbit) satellites, which orbit around the earth at a relatively low altitude between 500 and 2,000 kilometres, will play a special role. For example, the LEOs are necessary for open-air IoT applications where thousands of sensors transmit data from measurement stations. Here, especially in environmental protection and agriculture, applications are conceivable.

Agricultural machines are already using GPS technology to keep harvesting and mowing machines exactly on track by determining their position. In addition, GPS and 5G complement each other perfectly. Particularly where GPS reaches its limits, such as in innercity areas or in buildings, a high density of 5G nodes could efficiently complement GPS in the future.

The proposed fifth generation of mobile telecommunications, succeeding in the current 4G standard is expected to be deployed from 2020 onwards. In particular, 21% of the operators were expected to roll out 5G services in 2019, and an additional 86 % expect to be delivering 5G services by 2021. However, the majority of telecom operators do not expect to achieve total 5G coverage until 2028, while only 4% expect to have total coverage by 2025.

Concerning electricity consumption of 5G, estimates found that although there was optimism about the services and the interplay with edge computing enabled by 5G, there are significant concerns about rising costs. The move to 5G is likely to increase total network energy consumption by 150 to 170 % by 2026. The largest cost increases will be in macro, node and network data centres. Other studies based on simulations reveal that more than 50% of the energy is consumed by the computation power at 5G small cell base stations. Moreover, the computation power of a 5G small cell base station can approach 800 Watts when the massive MIMO (e.g. 128 antennas) is deployed to transmit high volume traffic. This clearly indicates that computation power optimisation can play a major role in the energy-efficiency of small cell networks, but also that the deployment of 5G poses additional burdens on the overall energy consumption of the cloud.

Al, Deep Learning, Deep Mind

In general terms, AI refers to a broad field of science concerned with getting computers to do tasks that would normally require human intelligence, hence to some kind of ability to plan, reason and learn, sense and build some kind of perception of knowledge, and communicate in natural language. An AI system combines and utilises mainly machine learning and other types of data analytics methods and computational algorithms to achieve artificial intelligence capabilities.

Currently, there are some fields of application with promising developments in the upcoming future: image and speech recognition, translations, Q&A and games. But the fields of applications might be much wider, and once the technology is mature it will find applications in almost any field from autonomous driving to predictive maintenance, smart housing, healthcare, etc.

AI models need to be trained, in order to be able to “learn” how to perform a certain task. One very promising field for instance concerns Generative Adversarial Networks, where two computational models compete against each other to achieve a certain objective. While doing so, they compute and analyse an extremely high amount of data. The model is promising (and currently also ethically controversial since it is the one used, for instance, to generate so-called deep fakes), but it requires days of continuous computation before it can reach satisfactory results. Similarly, the model training process for natural-language processing , the subfield of AI that focuses on teaching machines to handle human language, has reached several noteworthy performance milestones in machine translation, sentence completion, up to writing convincing fake news articles (the Open-AI’ GPT-3 model). Again, training the models requires a considerable amount of computation – hence, electrical power.

Studies performed a life cycle assessment for training several common large AI models (the Transformer, ELMo, BERT, GPT-2 and GPD-3) and found that the most computationally intensive process can emit from 26 (for the Transformer 65Mparameters model) up to 626,000 pounds of carbon dioxide equivalent, which is nearly five times the lifetime emissions of the average American car (and that includes the manufacture of the car itself), and equals the carbon footprint emitted by an average American for 17 years. Needless to say, the carbon footprint of natural language processing is computationally expensive and highly energy intensive. The significance of those figures is huge, especially when considering current trends in AI research.

5 General final conclusions: Demand and renewable energy

Most studies on the development of the energy demand of data centres assume that this demand will continue to rise significantly in the future. The forecasts range widely. The reason for the increase in energy consumption is the expected sharp rise in the demand for computing and storage capacity in data centres. Trends such as IoT, artificial intelligence, big data applications, video streaming and edge computing are expected to lead to an ever-increasing demand for data centre performance. In the coming decade, a significant risk exists that rapidly growing demand for information services—and compute-intensive applications like AI in particular—will begin to outpace the efficiency gains that have historically kept data centre energy use in check. Potential still remains for substantial efficiency gains but investments in next-generation computing, storage, and heat removal technologies will be required to avoid potentially steep energy use growth later this decade.

Several trends are shaping the future of data network electricity use. Global IP traffic doubled between 2016 and 2019, and is projected to double again by 2022.6 The nature of data transmission is changing rapidly, with traffic from wireless and mobile devices expected to make up more than 70% of total IP traffic by 2022, up from around 50% in 2019. Demand for data centre and network services will continue to grow strongly, driven in particular by rapidly growing demand from streaming video and gaming. Between 2019 and 2022, traffic from internet video is projected to more than double to 2.9 ZB, while online gaming is projected to quadruple to 180 EB. Together, these streaming services are projected to account for 87% of consumer internet traffic in 2022.

Rapid improvements in energy efficiency have helped to limit energy demand growth from data centres and data transmission networks. Strong government and industry efforts on energy efficiency, renewables procurement, and RD&D are necessary to limit growth in energy demand and emissions over the next decade. Data transmission network technologies are also rapidly becoming more efficient: fixed-line network energy intensity has halved every two years since 2000 in developed countries and mobile-access network energy efficiency has improved by 10-30% annually in recent years. However it is not sufficient.

The focus is to derive a trajectory for the ICT sector that supports a 1.5ºC limitation of climate change and the responsibility of the ICT footprint clearly lies within the sector. However, while striving to implement the decarbonization trajectory, it is important to understand that ICT, unlike many products and services sold in the world today, distinguishes itself by its double-edged nature. On the one hand, ICTs have an environmental impact at each stage of their life cycle, from energy and natural resource consumption to e-waste. On the other, ICTs can enable vast efficiencies in lifestyle and in all sectors of the economy through the provision of digital solutions that can improve energy efficiency, inventory management and business efficiency by reducing travel and transportation, e.g., teleworking and videoconferencing and by substituting physical products for digital information. The latter capacity is referred to collectively as second order or enablement effects.

Better modelling capabilities are required for decision makers to confidently evaluate future efficiency and mitigation options, so developing more robust and predictive methods that increase the frequency of bottom-up insights and overcome the limitations of extrapolation-based forecasts are a key priority for the energy analysis community. These models will be needed by policy makers and energy planners for monitoring future ICT energy use trends, understanding key energy use drivers, and assessing the effectiveness of various policy interventions for managing possible energy growth.

In spite that we are in a European analysis, because data centresare present nearly everywhere, such capabilities will be required at both national and global levels, and particularly for China, where data centre capacity is expanding rapidly. More reliable data should be developed and shared openly for the Asia Pacific region, and for China in particular, where data centre demand is growing rapidly. Lastly, better methods are needed for prospective analysis of next-generation computing, storage, and heat-removal technologies for accelerating investments in technologies that might avert future energy use growth. The analysts must work together to develop methods for modelling emerging trends, such as AI, the rollout of 5G, increased edge computing and blockchain, giving policy makers early insights into their possible energy use implications.

Beyond this, ICT has effects at the societal level by reshaping how people lead their lives. Such effects are much larger than the footprint itself and are important aspects to consider when optimizing the overall decarbonization of society. Some examples of the wider impacts of the ICT sector include, inter alia:

- virtual services replacing physical products, e.g., using e-readers instead of paperback books, optimizing entire sectors, like transport, industry, and agriculture;

- ICT can foster new sustainable lifestyles;

- significant improvement through digital services in the utilization of resources, e.g., infrastructure, vehicles and buildings.

Concretely this means:

- IoT-enabled building energy management systems;

- Smart irrigation;

- Energy-efficient frozen food;

- Managing urban traffic flow and congestion;

- Intelligent lighting;

- Intersection safety analytics;

The underlying idea is that global GHG emissions can be significantly reduced if existing and developing ICT solutions are used in other sectors (and ICT itself) to leverage their full potential in a smart manner. The positive contribution of assessed services based on ICT has been found to increase its direct footprint by an order of magnitude. However, such gains could be offset by rebound effects and even by other services optimized for other purposes (such as oil extraction). ICT has great potential, but as a common-purpose tool, it could be used for different purposes. Directed towards decarbonisation, its enablement effect is perhaps yet unleashed.

From the most important levers for reducing emissions:

-Consistent exploitation of existing and new energy efficiency potential

-Operation of digital infrastructures with renewable energies

-Reducing GHG emissions in the manufacture of end devices

- Extension of the useful life of end devices

Only renewable power sourcing will be capable to minimize the climate implications of unavoidable ICT energy use. To mitigate and curb the ICT explosive GHGEfootprint, through a **combination of:**

Renewable energy use,

Tax policies,

Managerial actions and

Alternative business models.

Annexe: Contributions of ICT to electrical energy consumption.

The technological developments that have occurred in recent years, together with those expected in the near future, are very different among the three components that interest us Data Centre, Networks and User devices, so it is necessary to treat them separately.

Data centres

It is currently impossible to speak of a reliable state of knowledge on the development and level of the energy demand of data centres in Europe. Although the last 20 years have seen major efficiency improvements, predictions suggest these may be coming to an end. If electricity continues to be a major source of data centre energy and is generated from non-renewable sources, data centre emissions could exceed the aviation industry which is currently responsible for 2% of annual human-generated CO2. The data centre energy projections have been wrong in the past. However, if efficiencies do not continue, we could see usage grow **within a range of 3-13% of global electricity by 2030.** Several scenarios could combine to hamper future improvements

The studies with regard to the GHG emissions of the data centres come to very different results. This is due in particular to the fact that there is little freely available data on data canters. The exact calculation bases are either not published in the studies under review or the calculation is only made very roughly with the help of exponential growth functions. The range for the energy requirement of the data centres is of around 200 to 1,000 TWh in 2020. With these values the entire life cycle is taken into account, including manufacture and transport of the devices and infrastructures.

The differences in the predicted energy requirements are due in particular to different assumptions about the development of the computing and storage capacity of the data centres and to different assumptions about the development of energy-efficiency. If it is possible to increase the energy-efficiency in data centres significantly, the increase in global energy demand will be much lower than with an only slightly improved energy efficiency. The current divergences are due to the fact that the same authors from the USA assume that the data centres will have significantly lower energy requirements, assuming very high global efficiency gains. These are mainly due to a transition to very large, so-called hyperscale data centres and other cloud data canters, which can provide computing power much more efficiently. . If current trends in the efficiency of hardware and data centre infrastructure can be maintained, global data centre energy demand can remain nearly flat growth in demand for data centre services continues to be offset by ongoing efficiency improvements for servers, storage devices, network switches and data canter infrastructure, as well as a shift to much greater shares of cloud and hyperscale data centres. Hyperscale data centres are very efficient large-scale cloud data centres that run at high capacity, owing in part to virtualization software that enables data centre operators to deliver greater work output with fewer servers. The shift away from small, inefficient data centres towards much larger cloud and hyperscale data centres is evident in the shrinking share of data centre infrastructure in total energy demand, given the very low power usage effectiveness of large data centres. According to current information, the energy demand in the usage phase is responsible for around 90 percent of GHG emissions. These are mainly due to a transition to very large, so-called hyperscale data and other cloud data centres, which can provide computing power much more efficiently.

Data centre energy usage is significant but historical efficiency improvements mean that growth has decoupled from energy consumption. Trends such as the cloud allow efficiency improvements to take place at huge scale but there are problems on the horizon. Moore's Law states that CPU performance per watt doubles every years. If data centre hardware continues to only be refreshed every 4.4 years, then major efficiency improvements may be missed. The introduction of new types of chips for specialist applications e.g. Graphics Processing Units (GPUs) for machine learning, could draw more power with unknown efficiency profiles. Approaching the physical limits of Moore's Law and new technologies such as machine learning mean historical improvements cannot be assumed. The data centre industry is changing rapidly and how that will affect energy profiles is uncertain.

Conclusion: *It can be stated that there are no uniform opinions and no reliable calculation results on the energy requirements and GHG emissions of the data centres. However a moderate increase in GHG emissions over the past 10 must be considered likely. Despite all the existing uncertainty, a magnitude of the global GHG emissions from the data centres in 2020, of 200 to 250 Mt CO_2e (including production) is considered plausible.*

Netwoks

As with the Data Centres, the estimates of the energy use of the networks differ widely between the different authors. The nature of data transmission is changing rapidly as more traffic flows through mobile devices and networks. Even for the development of the energy demand of network infrastructures worldwide, it cannot be said that the available studies come to similar results. The range of results is similar to that for data centres. This shift towards greater use of mobile networks may also have significant implications for the energy use of data transmission networks, given the considerably higher electricity intensities of mobile networks compared with fixed-line networks at current traffic rates. Mobile networks are rapidly shifting away from older 2G and 3G technology towards more efficient 4G and 5G. By 2022, 4G and 5G networks are expected to carry a combined 83% of mobile traffic, compared with less than 1% for 2G. 4G networks are roughly five times more energy efficient than 3G and 50 times more efficient than 2G. The overall energy and emission impacts of 5G are still uncertain. While a 5G antenna currently consumes around three times more electricity than a 4G antenna, power-saving features such as sleep mode could narrow the gap to 25% by 2022. Network infrastructure providers and operators are projecting that 5G could be up to 10 to 20 times more energy-efficient than 4G by 2025-30.

The available forecasts for the development of the energy demand of network infrastructures differ widely in some cases. The 2015 forecast by Andrae/Edler calculates the highest energy demand for the year 2030 at over 3,700 TWh/a worldwide

With almost 2,000 TWh/a, the 'shift project' is expected to have the highest forecast energy demand of network infrastructure by the year 2025. In contrast, the #smarter 2030 study assumes that the energy demand of network infrastructure will remain largely constant in the future despite significantly increasing data transmission rates

The International Energy Agency assumes an energy requirement of between 160 and 320 TWh per year. For GHG emissions, the range in the studies under consideration is between 140 and 300 Mt CO_2e. As with data centres, it is assumed that the energy demand in the usage phase is responsible for around 90 percent of total GHG emissions. In most cases, it is currently assumed that the energy requirements and GHG emissions of the telecommunications networks are divided equally between the mobile network and the fixed network. telecommunications networks For GHG emissions, the range in the studies under consideration is between 140 and 300 Mt CO_2e. As with data centres, it is assumed that the energy demand in the usage phase is responsible for around 90 percent of total GHG emissions. The energy requirements and GHG emissions of the telecommunications networks are divided between the mobile network and the fixed network. The exact division depends on the system boundaries. It can be assumed that the telecommunications networks, too, have moderately increased energy demand and GHG emissions in recent years and will continue to do so in the future. As with the data centres, an order of magnitude of 200 to 250 Mt CO_2e including the manufacture of the devices and systems is considered plausible for 2020.

A growth in energy demand is expected, especially for mobile networks The energy requirements and GHG emissions calculated in the studies also differ widely for telecommunications networks. In 2020, the energy requirements of telecommunications networks will be between 200 TWh and 550 TWh. In its report on digitization, the International Energy Agency assumes an energy requirement of between 160 and 320 TWh per year . For GHG emissions, the range in the studies under consideration is between 140 and 300 Mt CO_2e. As with data centres, it is assumed that the energy demand in the usage phase is responsible for around 90 percent of total GHG emissions. In most cases, it is currently assumed that the energy requirements and GHG emissions of the telecommunications networks are divided equally between the mobile network and the fixed network.

Conclusion: *Telecommunication's networks are between 140 and 300 Mt CO_2e. As with data centres, it is assumed that the energy demand in the usage phase is responsible for around 90 percent of total GHG emissions.*

End devices

Compared to the calculations for data centres and telecommunications networks, the results of the various studies on the end devices are more consistent. Deviations mainly result from the fact that different device types were taken into account. If only pure ICT devices such as desktop computers, notebooks, tablets and smartphones are taken into account, the result for 2020 is a range of around 320 to 700 Mt CO_2e. For consumer electronics devices (TV sets, set-top boxes, etc.), around 400 to 500 Mt CO_2e can be assumed in 2020.

In contrast to data centres and telecommunications networks, the proportion of GHG emissions from the manufacture and transport of ICT end devices (depending on the device type) is often over 50 percent of the GHG emissions over the entire life cycle. An increase in energy efficiency in use, an increasing number of devices and an increase in complexity in production mean that this proportion is expected to increase even further in the future

A look to digital industry

An energy requirement of 510 TWh per year is calculated for E&M end devices. The GHG emissions from ICT end devices amounted to 395 Mt CO_2e in 2015 and E&M end devices amounted to 420 Mt CO_2e. In the ICT sector, around 50 percent of the CO_2 footprint of end devices is due to manufacture and transport, in the E&M sector to around 30 percent. ICT devices and consumer electronics are currently responsible for the largest share of total GHG emissions from Digital Industry. The energy requirements in the usage phase of the individual devices decrease significantly due to the efficiency gains achieved. However, the total GHG emissions from end devices will probably continue to rise in the future, in particular due to the GHG-intensive production and the growing number of devices. A reduction in GHG emissions can therefore be achieved in particular if production takes place with fewer GHG emissions and the useful life can be increased through higher-quality, more durable equipment as well as recycling and reuse.

In entertainment electronics, televisions dominate with a relatively high energy requirement in the usage phase. The GHG emissions caused by production are estimated to be around 30 percent of total GHG emissions in this area

Conclusion: *The global GHG emissions from ICT and consumer electronics devices of around 900 to 1,100 Mt CO_2e appear plausible. Without consumer electronics, is believed that the GHG emissions are around 500 to 600 Mt CO_2e.*