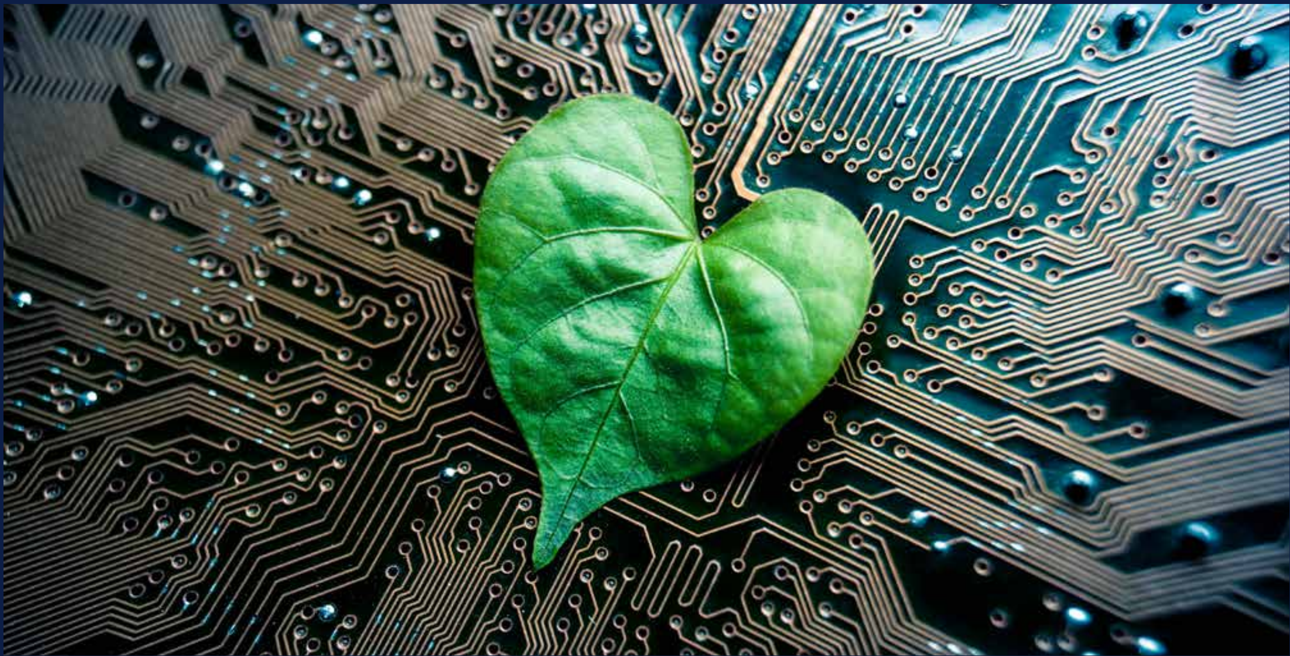
Makers & Shapers

# DIGITAL TECHNOLOGIES AND THE GREEN ECONOMY



# CONTENT

# **EXECUTIVE** SUMMARY

Credit: Ed Robinson/OneRedEye

The general agenda to achieve sustainable development (Paris and Glasgow conferences) is based on overall objectives such as 'Green Growth' and 'Green New Deal'. The role of digital technologies to achieve green growth is a topic of opposing opinions. Central to the debate is the question whether the reduction in non-green energy use through digital technology in the overall economy is larger than the increase in non-green energy consumption in the overall economy. We will present and discuss opposing angles and opinions given in literature on this question.

In this report we consider four effects on energy consumption of digital technologies: 1) the own energy consumption of digital technology; 2) the effect of digital technologies on energy efficiency overall, including rebound effects; 3) digital technologies driven substitution; and 4) Behavioural effects. An important observation coming from this is that the role digital technologies can play in the overall reduction of non-green energy in the economy is limited. Digital technologies can increase efforts to improve their own energy efficiency and use renewable energy in their own operations or they can do so in their product life cycles. However, the sector's energy consumption is a relatively low part (4-9%) of all electricity use in the economy. The use of energy in other sectors, through substitution effects with rebound effects and behavioural effects, depends mainly on the possibilities (high or low-price elasticity compared to output elasticity) and initiatives of these sectors and government measures.

Four extreme scenarios are developed based on these effects: 'Compensation' (low energy efficiency in the digital technologies sector, which is compensated by high energy efficiency in all other sectors, also thanks to the use of digital technology solutions), 'Utopia' (high energy efficiency of digital technologies, which is taken up in the overall economy to reduce energy use), 'Dystopia' (low energy efficiency of digital, and low energy efficiency in other sectors), 'Deprivation' (high energy efficiency of digital, with the other sectors deprived from using it), along two axes: Energy Efficiency of Digital Technologies and Economy-wide Energy Efficiency.

Through existing and introduction of new measures, policymakers (the 'shapers') could potentially lead us towards an ideal scenario where almost all effects can be directed positively, while limiting the costs imposed on the economic growth and energy prices.

This would require support to the digital technologies sector to strongly increase their energy efficiency and at the same time take measures to use these energy intensive digital technologies to reduce energy consumption by substitution in other sectors whilst limiting possible rebound effects.

There are several existing initiatives and regulations in this direction that should be continued and reinforced by new measures, established in a dialogue with both industry and societal organisations. Some directly aim at industry sectors, others aim at empowering consumers and making them aware that their behaviour can have an impact on achieving green growth, through traceability, transparency and visibility of value chains and production processes (e.g., Potočnik, 2019, p. 25). The latter could limit rebound effects. A key new initiative is the Sustainable Product Initiative (SPI) that envisages a Digital Product Passport (DPP) exactly for the purpose of traceability and transparency. However, it is important to stress that measures should be highly differentiated by industrial sectors, also to minimise imbalances at global level and possibly flight of energy producing and energy intensive business to less regulated countries.

These existing or planned measures could be reinforced to help moving further towards the Utopia scenario by, for example, making potential energy efficiency an evaluation criterion for research in all sectors (Schwartz et al, 2019). In addition, regular detailed reporting on tech companies' advancements towards energy efficiency could have a positive effect.

It must be noted that most business leaders of technology companies are fully aware of the importance of Environmental Social Governance (ESG), a new important evaluation metric applied to their companies, and they are willing to contribute to create a Digital Technology-empowered ESG. There are also indications that businesses are not afraid of more regulation aimed at increasing sustainability if this would also increase predictability.

## THIS REPORT ENDS WITH THE FOLLOWING CONCLUSIONS:

1. The lack of an agreed framework of measuring and modelling digital impact on energy consumption in various sectors leads to many opposing views. To have a fact-based discussion, an agreed framework should be put in place based on international standards to model and quantify the impact of digital technology on energy consumption in various economy sectors.

2. Although a reduction of energy consumption of digital technologies as such is relevant and should be pursued, this energy consumption is less than 10% of the total energy consumption.

3. The impact of the application of digital technology on energy consumption varies strongly across economic sectors. Therefore, the focus should be on those sectors where the potential gain is high. For example, the COVID pandemic showed that moving physical meetings online leads to significantly less travel resulting in substantially reduced energy consumption.

4. When applying digital technology in specific sectors, attention must be paid to possible rebound effects, whereby the energy savings achieved in one domain are offset by reuse of energy in another domain. These are linked to both behavioural (i.e., consumers' substitution waves) and structural factors (i.e., energy output elasticity of certain sectors) that can be contained only through strong interventions such as taxation and incentives.

# INTRODUCTION

Greenhouse gas (GHG) emissions should be reduced by 45% by 2030 (compared to 2010 levels) to meet the goal of earth temperature increase staying within the target of 1.5° (IPCC, 2018), a target that is part of the general agenda to achieve sustainable development (Paris and Glasgow conferences). Overarching objectives such as 'Green Growth' and 'Green New Deal' presuppose that economic growth can be decoupled absolutely or at least partially from non-green energy consumption. Absolute decoupling occurs if the non-green energy efficiency of the economic system increases faster and in greater proportion than economic growth (energy consumption). If energy efficiency increases, but economic growth is at the same time larger and faster, then only relative decoupling occurs. The reasons for this are related to various factors and to the elasticity of the demand for energy to price and output (read economic growth).

The chances of achieving decoupling thus depend on what happens in all economic and social activities and cannot be shaped just by the digital technologies industry and the related digitalisation processes. Digital technology activities are not a special case, except that they not only consume energy, but can also be used to reduce energy use in other sectors. In this respect, digitalisation has raised great hopes that it could contribute to reduce emissions and demand for energy. The phenomenal growth of the digital sector and the lack of tangible empirical evidence on positive energy efficiency spill-over effects, however, have led also to criticisms that the sector itself increasingly consumes energy and does not enhance the energy efficiency of other sectors sufficiently.

Twenty years ago (Berkhout and Hertin 2001) it seemed obvious that virtualisation and dematerialisation of production and consumption processes, together with virtualisation of mobility and smart transport, would reduce the consumption of energy and the GHG footprint across the board. Videoconferencing has without doubt a smaller footprint than a conference in Brussels where dozens of delegates fly in from 27 different countries. Virtual goods replacing physical goods should also produce clear gains in reducing both energy consumption and usage of natural resources. Virtualisation and simulation (i.e., Digital Twins) of manufacturing processes should enable faster development of design and reduce the consumption of energy by cutting down some analogue parts of such processes. More generally, digital substitution of processes in traditional sectors and the digitally driven transition from agriculture and manufacturing towards the services sector, could lead to reduced energy consumption since the service sectors are less energy intensive than agriculture and manufacturing[1]. On these grounds the digital industry has made forecasts that digitalisation would reduce energy demand and emission for entire economies (GeSI[2] and Accenture, 2015; GeSI and Deloitte, 2019). And yet, especially in the last five years a polarised and heated debate emerged that challenges all the promises of digitalisation and claim that digitalisation is heavily contributing to increased energy consumption (see the Box 1). This debate revolves around two key effects: the energy consumption of Digital Technology itself and the energy savings that Digital Technologies could produce for all other sectors of economy and society. We treat these two effects in chapter one.

On the net effect of digital technologies on energy consumption – consumption by digital technologies minus energy savings induced in other sectors – there are contrasting narratives that come to different conclusions, produce opposing estimates on the same topic and thus rather contribute to polarisation than to an informed debate. There are two main reasons for this situation. First, the phenomenal growth of digital production and consumption and the ongoing digital transformation accelerated by the effects of COVID-19 raise reasonable concerns about the energy consumption by Digital Technology and digitalisation. Second, current attempts to come to definitive answers are fraught with measurement and modelling problems that, in our view, will not be solved in the short term.

**Digital Technologies** energy consumption. Digital industry estimates that the sector consumes about 4% of global electricity demand and 1.4% of global GHG emissions (Malmodin & Lundén, 2018). The European Commission, using an NGO source, reports instead a consumption of 5-9% of the world's total electricity and more than 2% of global emissions (2020, p. 7).

**Environmentalists** are claiming that the current digital overconsumption trend is not sustainable (The Shift Project, 2019). They called the digitalisation a "climate disaster"[3]. An article published in Nature Climate Change in 2018 has it all in the title "Bitcoin emission alone could push global warming above 2°C" (Mora et al., 2018). Another report claims that video streaming alone generates as much GHG emissions as the entire country of Spain[4].

**Data centres.** On their impact on energy consumption one finds, even in the scientific literature, opposing and contrasting positions. Some claim that they have greatly increased their energy efficiency (Coroama and Hilty, 2014; Avgerinos et al., 2017), while others calculate or forecast that data centres will greatly increase energy consumption (Salahuddin & Alam, 2016; Koot & Wijnhoven, 2021).

**Blockchain.** The claim about cryptocurrencies (Mora et al. 2018) wrongly charges blockchain as a source of energy consumption, since most of the cryptocurrencies' energy consumption happens during the mining process (Sedlmeir et al., 2020). Once coins have been issued, the energy required to validate transactions is minimal.

**Artificial Intelligence** (AI) and Natural Language Processing (NLP). Strubell et al. (2019) argue that AI and NLP are environmentally unfriendly. Another group of researchers, however, expect AI and NLP to reduce energy consumption (Schwartz et al., 2020).

**Box 1** Examples of opposing estimates and claims

To shed some light in the debate we present in section 1 from literature study, a consistent and reliable taxonomy of the effect mechanisms through which digitalisation can impact energy consumption directly or indirectly. Based on this taxonomy we propose scenarios, taking into account some key structural aspects of energy demand and consumption and give an assessment of these scenarios. We conclude with their implications and possible levers to steer future developments towards the most desirable outcomes. This can help to reason and envisage how different effects can be fostered or contained.

**1** The worldwide energy intensity in industrial production is 0.12 kgoe/$ (kilogram oil equivalent per dollar), in agriculture 0.036 kgoe/$ and in services 0.016 kgoe/$ (see: https://www.enerdata.net/consulting/energy-efficiency-evaluation.html ).

**2** GeSi stands for Global e-Sustainability Initiative, a cooperation of about 40 IT and telecommunication firms.

**3** https://www.theguardian.com/technology/2019/sep/17/tech-climate-change-luddites-data

**4** https://theshiftproject.org/wp- content/uploads/2019/07/Excutive-Summary_EN_The-unsustainable-use-of-online-video.pdf

# **A TAXONOMY** OF EFFECTS

In this taxonomy, we focus on the following effects: I. Digital technology's energy consumption; II. Digital technology's effect on energy efficiency of other sectors and rebounds; III. Digitally driven substitution; IV Behavioural effects. I and II are the most debated and contested effects in the polarisation described in the introduction. These are first order effects as their impact on energy consumption is to some extent direct. Effects III and IV are transformational second order effects. Their manifestation is mediated by changes in other relevant variables and processes.

## **EFFECT I:** DIGITAL TECHNOLOGY'S ENERGY CONSUMPTION

We adopt the definition of Digital Technology proposed by the OECD that includes digital technologies manufacturing, software publishing, telecommunications, information technology and other information services (OECD, 2015). Across these four sub-sectors the consumption of energy can be attributed to the operation, manufacture, and disposal of digital equipment. The consumption of energy by the digital technology sector depends on its growth and the degree of energy efficiency. Without changes in the energy efficiency of digital technology itself, its energy use can be expected to relate linearly to its growth. If energy efficiency of digital technology increases, it can substantially reduce the overall energy consumption by the sector. There are controversial positions and estimates on the capacity of the digital technology sector to increase its energy efficiency, due to uncertainties on technological processes in the models used and measurement difficulties. As seen in Box 2 most efforts have focussed on operational energy use, overlooking (for lack of data) manufacturing and disposal use of energy that can be a non-trivial component of direct energy consumption.

The literature considers three main categories: devices (e.g., phones, computers, tablets), data centres (e.g., servers, data, computing units) and communication networks (e.g., wireless, data transport). From these three categories, devices represent the most important source of energy use, with estimates between 38% (Heddeghem et al., 2014), and 50% (Andrae, 2019). Focusing on the period 2007-2012, Heddeghem et al. (2014) show that the annual growth of all three digital categories (devices 10%, data centres 5%, and communication networks 4%) is higher than the growth of worldwide electricity consumption. Considering the trends, personal devices will probably become more efficient. Andrae and Edler (2015) with revision in Andrae (2019) present three scenarios for the global electricity consumption of digital technologies between 2010 and 2030. In all three scenarios the sector's electricity consumption increases – from 1,500 TWh (8% share of global electricity consumption) in 2010 to 5,700 TWh in 2030 (14% share of global electricity consumption). Use stage power by data centres is considered one of the most important drivers for digital electricity use in the future. Instead, the use stage power of digital consumer devices, which represents the largest share of direct energy use today, is expected to decrease thanks to advanced power saving features. An earlier study (Corcoran 2013) concluded that digital technology's consumption of energy will not slow down until 2030. There are also some studies focussing on specific digital technologies or services. One on energy demand of internet data flows calculated the energy consumption of a three-day Internet video transmission between Switzerland and Japan as amounting to an average of 0.2 kWh/GB (Coroama, 2013). Another study (Aslan et al.2018) estimated that transmission networks show a halving of energy intensity every 2 years. Aslan et al (2018), however, also argue that the sharp increase of the data flows completely off-set the efficiency gains.

**Box 2** Estimates of digital technology's energy consumption

## **EFFECT II:** DIGITAL TECHNOLOGIES' EFFECT ON ENERGY EFFICIENCY AND REBOUNDS

This is the effect that digital technologies may have on the efficiency of energy use by other sectors and in residential life through the three 'Ds' (Sui & Rejeski, 2002). Decarbonisation through energy monitoring and management applications leading to less energy consumption; Dematerialization (i.e., e-book instead of printed book); and Demobilization (i.e., teleworking and teleconferencing instead of travelling).

Digital technologies also enable virtualisation (i.e., decoupling of products and services from material usage, more efficient materials handling and more). Bieser and Hilty (2018) give a more accurate classification based on seven application domains (Table 1). Most studies cover the application domains: virtual mobility, smart transport, and virtual goods, followed by smart buildings, smart energy, smart production, and shared goods. Other less frequently assessed domains are smart agriculture, smart water, or waste management.

Digital technologies change both the patterns of production (e.g., by changing manufacturing processes) and of consumption (e.g., by changing individual media use). As can be expected, changes in production and consumption patterns are closely interrelated. For example, optimization of logistics has decreased the cost of logistic services such that e-commerce retailers can afford to offer free delivery and return to consumers, which dramatically changed consumers' online shopping behaviour (Bieser and Hilty, 2018).

Many assessments investigate how digital technologies change patterns of production using a product-oriented modelling approach. Focusing on production enables understanding environmental consequences of functionally equivalent production systems, with or without the application of digital technology. A change in consumption behaviour (e.g., people reading e-books instead of printed books), however, is treated as an exogenous

| Application Domain | Description | Example Use Cases |
|---|---|---|
| Virtual goods | Replacing physical goods with ICT-based services | E-books, online newspapers, music and video streaming |
| Shared goods | Coordinating access to goods, increasing utilization | Sharing platforms |
| Virtual mobility | Replacing physical travel with ICT-based remote action | Video conferencing, e-commerce, e-health, distance learning, remote maintenance |
| Smart transport | ICT-enabled change of the process of transporting people or goods | Route optimization, traffic flow management |
| Smart production | ICT-enabled change of the processes and business models of production | Automation of production processes |
| Smart energy | ICT applications in the energy sector (mainly electricity supply) | Smart metering, demand side management, distributed power generation |
| Smart buildings | Change of building management enabled by ICT | Smart heating, smart lighting |

**Table 1** Main application domains for Digital Technology energy efficiency
Source: Bieser and Hilty (2018)

variable. Hence, the consumption side is underexplored whilst both perspectives are required to fully understand how digital technology can change economic processes and their environmental impact.

While these theoretical grounds for expecting digital technology to increase energy efficiency in other sectors are sound, the evidence on this effect is still inconclusive. The picture is complicated by rebound effects (Box 3). Most literature results are much heavier on conjecture and discussion than on results (Gossart 2015). Several authors argue that use of digital products and processes are particularly prone to high rebound effects (see for instance Santarius, 2014). The reason is that increases in energy efficiency foster energy consumption via various mechanisms, such as a re-spending of savings and a substitution of other production factors by energy. More generally, economic historians argue that the history of economic growth is a history of rebound effects (i.e., Ayres & Warr, 2009). This is clearly related to the issue of energy output elasticity.

Most studies in this domain are predictive rather than empirical due to difficulty in measurement. For buildings, Meyers et al (2010) estimate that average U.S. residences waste around 40% of their primary energy consumption due to inefficiency. Much of this waste is addressable by smart technology interventions. Smart energy feedback can potentially reduce energy demands in the housing sector in a massive way (Buchanan et al., 2015; Jensen et al., 2016; Malmodin and Coroama, 2016; Nilsson et al., 2018). Similarly, in manufacturing, industrial control systems increase efficiency, fault-detection, and productivity, reducing per-unit energy consumption and waste (Davis et al, 2012). Simulations and predictions show that digitalization can increase energy efficiencies in agriculture, mobility, housing, and industry (Horner et al., 2016; Mickoleit, 2010). On the other hand, findings from a living lab study showed that the energy consumption remains roughly the same (Buhl et al., 2017). The literature on the impact of e-commerce tends to find positive effects on energy efficiency, but results are not universal and are very sensitive to assumptions (Horner, 2016). E-commerce may make 'last mile' transport more efficient due to optimization of shipping routes by delivery companies, but it can increase energy use by substituting air for ground freight.

**Box 3** Digital technology's effects on energy efficiency and rebounds

The results on rebound effects are varying from off-setting energy saving to low effects (see Jenkins et al., 2011, Goldstein et al., 2011; Nadel, 2012). For instance, despite the improved availability of video conferencing systems, the number of international scientific conferences is increasing (Coroama et al., 2012, 2013). Or, the number of printed books is not declining, while e-books and reading of websites are increasing. The data traffic associated with streaming can offset the gains through diminishing DVD purchases or rentals (Shehabi et al., 2014, Cisco, 2019). The energy intensity of CPU processors decreases by half every 1.5 years (Koomey et al. 2011), but the processing capacity doubles also every 1.5 years, outbalancing the potential to save energy (Lange and Santarius, 2020).

## **EFFECT III:** DIGITALLY DRIVEN SUBSTITUTION

The substitution effect can be decomposed into three distinct mechanisms:

1. Digital technologies itself substitute traditional sectors. One clear example is online travel-related platforms (i.e., booking.com, Airbnb, etc.) having largely replaced the traditional travel agency sector. In principle, this should reduce energy consumption by eliminating the activity of many brick & mortar establishments. However, even in this case rebound effects (see Box 3) can happen and the net results are uncertain. The increase in volume of digital services may end-up consuming more energy than the traditional services they displace.

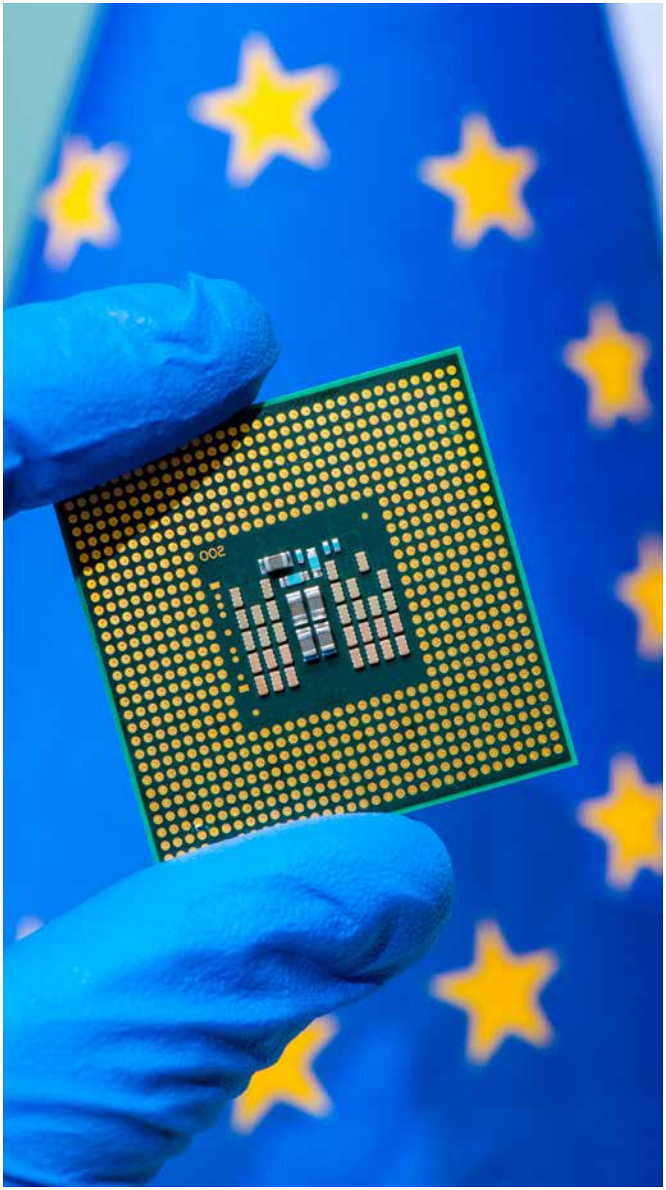
2. Digital technologies substitute production processes within other sectors. For example, deployment of Industry 4.0 and 5.0 solutions or of virtualisation and simulation (Digital Twins) inside manufacturing processes. This should enable reduction of energy consumption through faster design and cutting down analogue parts of the production process. This is a promising path but still with low take-up, and hence no data is available on the effects. Moreover, even in this case, if energy output elasticity is high, the energy efficiency and price effects can be reabsorbed by other energy-intensive activities.
3. 'Tertiarisation' (see for instance Lang et al 2020), the path whereby digital technology favours structural change within economies so that activities and value added from agriculture and manufacturing shift towards services. This is in terms of size a potentially large indirect effect and is most debated in literature. So, below we focus on this mechanism.

According to the OECD (2015), digitalisation favours a shift towards the service sector. Since the service sectors are less energy intensive than agriculture and manufacturing, this sectoral change may have positive impact on reducing the energy intensity of economic systems. The worldwide energy intensity in industrial production is 0.12 kgoe/$ (kilogram oil equivalent per dollar), in agriculture 0.036 kgoe/$ and in services 0.016 kgoe/$ [5] This is, however, a second order effect mediated by the structural transformation of economic sectors that is varied in time and space (Lange et al 2020). This effect finds in principle theoretical support from a classic of economic theory, the so-called Environmental Kuznets Curve (EKC) whereby also environmental impact is seen as cyclical (Stern, 2004). According to this narrative, emissions are low in agrarian economies, rise with industrialisation and fall again with the post-industrial transition to a service economy. As shown in Box 4, however, empirical evidence does not seem to support this thesis.

While some studies find a reverse U-shaped relation between economic growth and energy consumption, for instance Yandle et al. (2002), others contradict it and show that the curve does not hold across time, space, and sectors (see for instance Caviglia-Harris et al. 2009). The reasons depend on two factors, (i) whether digital technology does contribute to a shift towards the service sector, and (ii) whether this does reduce energy consumption because the shift affects the energy intensity of the new services. The first effect varies across countries. In China and India, digital technology development occurred at the same time as a steep increase in manufacturing, also due to the relocation of manufacturing from OECD countries to these two counties (OECD, 2019). On the other hand, digital technologies fostered the growth of the service sector in EU countries and other more advanced OECD countries (Eurostat, 2021; OECD, 2017).

But an absolute shift to the service sector is not occurring. In many countries the service sector grows but agriculture and manufacturing are not declining (Eurostat 2021; World Bank, 2020). Evidence on the second factor is equally mixed. Given the lower energy intensity of the service sector, the process of shifting from agriculture and manufacturing towards services should reduce energy consumption. Yet, apparently the digitally enabled new services are more energy intensive than traditional services (Mulder et al., 2014). The observations that the shift towards the service sector is relative rather than absolute and that new digital services are more energy intensive run counter the ECK hypothesis.

**Box 4** The empirical evidence on the substitution effect



Source: EC - Audiovisual Service

## **EFFECT IV:** BEHAVIOURAL EFFECTS OF USE OF DIGITAL TECHNOLOGIES

This effect (often also called 'systemic change'), is a second order effect, mediated by behavioural change that can either have positive or negative effects on digital technology use. Literature on it is mostly speculative and hence inconclusive. We can only illustrate it with examples. On a positive side, e-commerce and home delivery make proximity to traditional retail outlets less important, telework results in less commuting, or driverless vehicles allow for more productive use of the commuting time. This may create new behavioural patterns of individuals and organisations that can contribute to reduce energy consumption. But, by the same token, individual level behaviour can be dysfunctional (separate delivery – and return – of many small products; increased driving in leisure time). Digital technology can also empower informed consumers to improve their choices.

But digital consumerism may also result in unnecessary replacement of devices by 'more fashionable devices' that increase energy use through production costs. This may be further stimulated by the industry's behavioural practice of not making it easy for consumers to get digital devices repaired, in contrast with the EU objectives of going towards a circular economy. In addition, technological change may be designed such that devices need to be replaced. For instance, it is expected that 5G and Wi-Fi 6 will force users to replace equipment soon (most, even new smartphones, tablets, and PCs are not 5G and/or Wi-Fi 6 compatible).

**5** See: https://www.enerdata.net/consulting/energy-efficiency-evaluation.html

# FROM THE **EFFECTS** TO **THE SCENARIOS**

## SUMMING UP THE EFFECTS AND BACK TO THE CONTENDERS' VIEWS

The two main mechanisms worth focussing on are Effect I and Effect II, for they are direct and entail some level of uncertainty, but not as much as Effect III where the empirical evidence does not seem to support any of the three mechanisms. The behavioural effect is important but still analysed only at speculative level. The graph below summarises the discussion presented in the previous section.

Digital Technology's consumption of electricity is growing exponentially and seems to cancel out its energy efficiency gains, and physical capital seems to complement rather than substitute energy use. The main uncertainty is whether in the future innovation in digital technology will reduce the sector's energy consumption faster than the sector's own growth.

There are strong theoretical and modelling arguments supporting the idea that digital technologies can increase the energy efficiency of other sectors. The empirical evidence on the overall effect, however, is mixed and inconclusive. The main uncertainty is on the occurrence and extent of rebound effects that depend on the structural relation between economic growth and demand for energy.

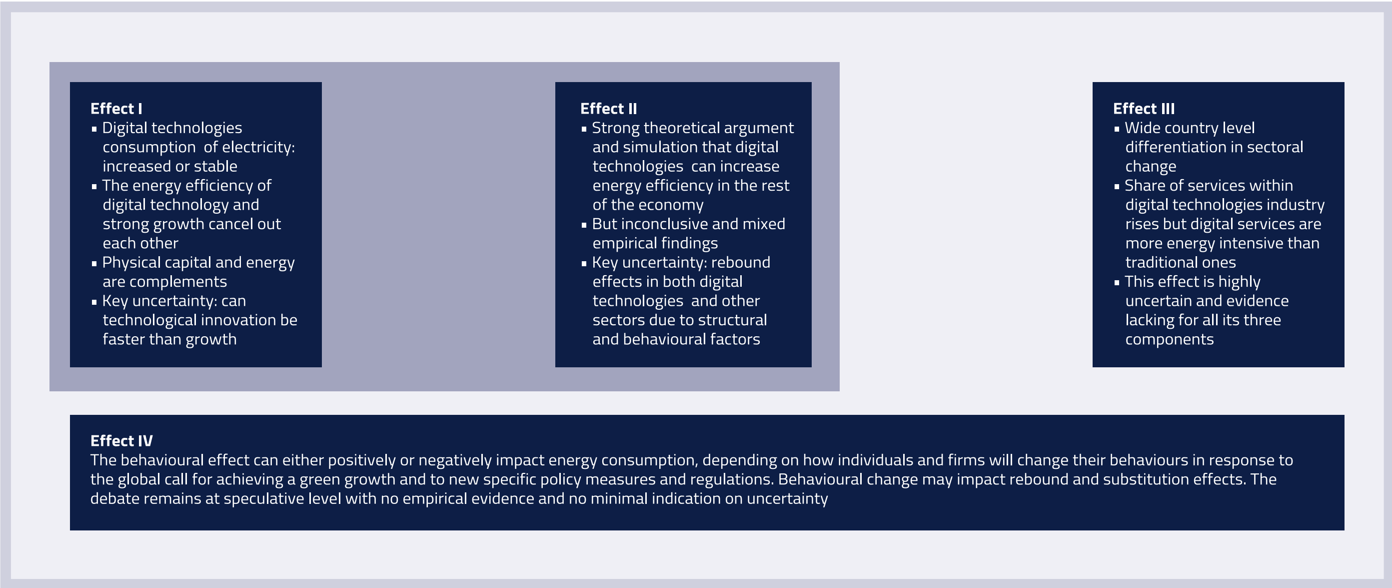



**Figure 1:** Summary of effects. Source: Own elaboration

Digital industry and environmental organisations are emphasising different aspects of the two main effects. Industry, while also trying to show that currently its own consumption of energy is not as high as claimed by its opponents, focuses on (i) projecting that technological innovation will increase energy efficiency in the digital sector and on (ii) showing the potential of digitalisation in reducing the energy consumption of other economic sectors. On the contrary, environmentalists point to how much energy digital industry is currently consuming, including for certain specific applications such as blockchain and video streaming. They also stress the importance of rebound effects that can lead to more energy use and consumption of goods.

Governments as shapers face a complex optimisation problem with several constraints. They cannot maximise economic growth at the expense of environmental sustainability, but neither can they maximise the latter at the expense of the former. Most potential effects are surrounded by large uncertainties and entail difficult trade-offs. By using a scenario approach, we attempt to chart such uncertainties and trade-offs, to support regulation based on relevant conclusions.

## THE PROPOSED SCENARIOS

The proposed scenarios, depicted below, are defined by two axes: the energy efficiency of the digital technology sector on the horizontal axe, and economy-wide energy efficiency on the vertical one, both of which can vary from low to high. The horizontal axis coincides with Effect I, whereas the vertical axis relates to Effect II in a broader perspective.

In absence of interventions, the variation on the horizontal axis depends on how fast technological innovation and energy transition in the digital technology sector reduce its energy consumption and on the rate of growth of the sector. The variation on the vertical axe is more complex and is not impacted solely or even mostly by the contribution of digital technologies to the energy efficiency of other sectors. It depends on the sector, other technologies and on rebound effects and structural rigidities.

The empirical analysis of the long-term relation between energy demand (consumption) and energy prices and output (i.e., growth) shows that such demand has low negative elasticity to price and high positive elasticity to output. On average one could say: if the price of energy goes up notably the demand for it goes down only slightly. On the contrary, if GDP goes up by 1%, the demand for energy increases by 1.5%. This applies on average to the economy as a whole, but elasticity to output is higher in the industrial sectors in comparison to the residential sector, and the latter seems also more sensitive to price. Within economic sectors, there are more energy intensive ones (i.e., non-ferrous metals, iron and steel, chemical and petrochemical) where the elasticity to output is higher compared to less energy intensive ones (i.e., fishing, mining, commercial and public services, etc.). The structural reason behind this is that energy intensive economic production processes require energy as a key input that cannot be substituted by either labour or capital. Hence, price regulation would be ineffective for very energy intensive sectors but may work with less intensive sectors and in the residential domain. For the high energy intensive sectors, it might be more appropriate to stimulate technological innovation to improve energy efficiency. Obviously, industry-wide structural change (towards less energy intensive industrial sectors and more service sectors over all industries) could improve the situation, but this is not the kind of change that in liberal market democracies can be made by shapers without the help of makers. Such a change depends on structural transformation processes and on behavioural changes such as consumers increasingly demanding products that are less energy intensive.

There are clear implications of the above discussion on the potential impact that digital technologies and digitalisation can have on other sectors. If digitalisation increases energy efficiency,

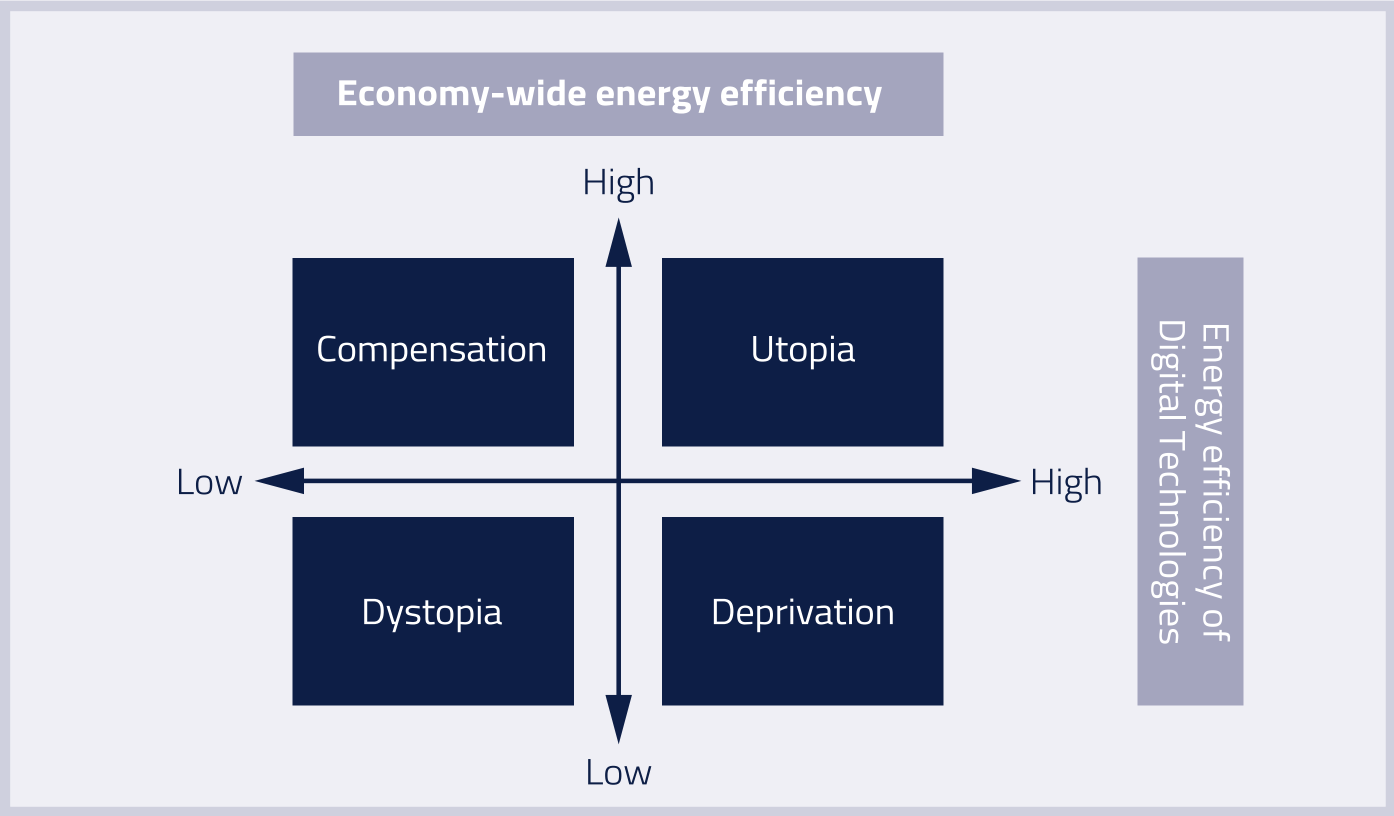



**Figure 2** The scenarios. Source: Own elaboration

it may bring greater economic growth and hence increased energy demand (Lange et al. 2020, p. 6). Under such conditions, any energy efficiency gain produced by digitalisation may be absorbed by more demand and neutralised. In conclusion, if digitalisation were to contribute to the desired decoupling efforts, then the digital sector should: a) increase its own energy efficiency and shift to renewable energy faster than its growth (horizontal axe); and b) contribute to the energy efficiency of the rest of the economy by an order of magnitude greater than the potential rebound effects (vertical axe). Clearly, two daunting tasks, especially the second one. This challenge shapes how the four scenarios' storylines are characterised in the next paragraph.

Finally, the scenarios are defined by two endogenous dimensions, whereas the possible exogenous regulatory interventions are included in the scenarios' storylines. Such interventions can vary from laws, taxes, or price regulations to new public procurement rules and targeted R&D subsidies. Or they can be softer and leverage a wider portfolio of interventions such as standards, codes of conduct, and measures aimed at increasing transparency and consumer awareness and empowering them to make better environmental choices. These could be matched by self-regulation initiatives by the digital sector and other economic sectors.

## SCENARIO STORYLINES

**Compensation.** From the perspective of common public good, this scenario is called 'Compensation' because the cost of low energy efficiency in the digital sector is compensated by high energy efficiency in the rest of the economy. Energy pricing measures and R&D funds in support of technological innovation in other sectors, matched by taxes on residential consumption of energy, manage to contain rebound effects and break rigidity in elasticities, bringing industry and residential services toward energy efficiency. Digital technologies will have a positive contribution to the energy efficiency of other sectors. However, the high energy intensity of the digital sector will hamper the technological innovation in other sectors, hence resulting in lower energy efficiency than possible in the other sectors. On the other hand, raising energy consumption in the digital sector might to some extent be covered by transition towards renewable sources of energy. In this scenario the increase of energy consumption could be tolerated because it positively contributes to energy efficiency gains in the rest of the economy. The decoupling of energy and growth, however, is only partial and unstable, as more digital services are brought to the market which are more energy intensive than traditional services. Hence, overall energy consumption decreases only to a certain extent. Innovation towards energy efficiency in the rest of the economy may create more jobs at mid-term, but short-term increases in energy prices could cause problems of social cohesion both at residential and industrial level. Increasing energy prices become a constraint for lower income families and can create problems to small firms in less innovative sectors that may result in growing unemployment. The measures charactering this scenario (taxes, regulation of prices, and public subsidies) might partially constrain economic growth. The chances to achieve climate goals in this scenario are small, which also might affect social cohesion.

**Utopia.** This scenario is deemed utopian in view of the structural rigidity in the relation between growth and energy demand illustrated earlier. Endogenous technological innovation in both the digital sector and in all other sectors of the economy in combination with strong regulatory and support measures achieve the absolute decoupling between economic growth and energy consumption. The digital sector greatly reduces its own energy-intensity and consumption of energy through technological innovation and moves fast in the direction of energy transition. This reduces the size of Effect I and has positive effects on the energy efficiency of the rest of the economy. The regulatory measures are like those of the 'compensation' scenario but stronger and with wider and deeper effects. Potential energy efficiency will be an evaluation criterion for R&D support for technological innovation. Public procurement rules related to energy efficiency and standards are introduced that change government practices. Ad hoc taxes on substitution of digital devices are introduced, and energy price regulation is in place. Energy consumption decreases in all sectors of economy and society at the cost of only a partial constraint on economic growth. Tech companies will regularly report on their performance in terms of energy efficiency. In the short-term, social cohesion may slightly worsen due to increasing energy prices and to taxes on consumption of digital devices and services. However, this is temporary and the clear view of achieving IPPC climate goals might take away fierce social polarisation and fear for climate disasters.

**Deprivation.** From the perspective of overall benefits for the common public good, in this scenario the gain from improvements in the digital sector are dissipated and absorbed by the structural incapacity of the energy intensive sectors to reduce energy consumption. The common public good is deprived, by foregoing a potential benefit from the energy efficiency of the digital sector, thus bearing an increasing cost. Some measures and endogenous technological development bring the digital sector on the path of reducing its energy intensity and of increasing its potential contribution to the energy efficiency of other sectors. In the absence of hard interventions, self-regulation initiatives and increased consumer awareness may bring about behavioural change at least for the consumption of digital products. These measures, however, are insufficient to contain rebound effects and to break the rigidity of elasticities in the economy, especially in the more energy intensive industrial sectors. There is basically no decoupling effect because the gain in the digital sector and through more efficient products is too small to compensate the low energy efficiency in industry. Energy consumption goes up and energy transition slows down, since these two positive effects occur only in the digital sector, and green innovation slows down too. The effect of pricing and markets may keep social cohesion stable in the short term but may worsen if and when the effects of pollution and climate change start to be felt by the population. In this scenario there are no constraining effects on economic growth.

**Dystopia.** This is clearly a dystopic scenario with negative decoupling in the sense that economic growth is greater and faster than any advancement in reducing the energy intensity of both digital technologies and other economic sectors. In absence of a coherent set of measures, economic growth is left unfettered and becomes entropic. The economy grows but at the cost of the dissipation of energy and natural resources. Energy consumption increases and there is basically no green transition and no green innovation. The relation of this scenario with social cohesion is more ambivalent than what we have seen for Deprivation. In the short-term, economic growth, stable or decreasing energy prices, and no consumption taxes may even improve social cohesion. But in the medium- and long-term it might radically worsen as a result of increased pollution, the consequences of climate change and shortages of material resources.

Several existing initiatives and regulations fit well in scenarios aiming at improving overall energy efficiency. These include the Circular Economy Action Plan CEAP (European Commission, 2020b) reinforced in Council Draft Conclusions on Making the Recovery Circular and Green (Council of the European Union, 2020); the Framework for eco-design requirements of energy-related products (European Parliament and Council, 2009); and the WEEE directive on waste of electrical and electronic equipment (European Parliament and Council, 2012). Other initiatives focus on rebound and behavioural effects, aiming at empowering consumers and making them aware that their behaviour can have an impact on achieving green growth, through traceability, transparency and visibility of value chains and production processes (Potočnik, 2019, p. 25). We can also note two ancillary initiatives: the Communications on Strengthening the role of consumers in the green transition (European Commission, 2020b) and on Strengthening consumer resilience for sustainable recovery (European Commission, 2020c). A key new initiative is the Sustainable Product Initiative (SPI) that envisages a Digital Product Passport (DPP) exactly for the purpose of traceability and transparency. It is, however, important to stress that measures should be differentiated by industrial sectors, also to minimise imbalances at global level and possibly flight of energy producing and energy intensive businesses to less regulated countries.

Furthermore, it must be noted that most business leaders of technology companies are fully aware of the importance of Environmental Social Governance (ESG), which is by now a new important evaluation metric applied to their companies and are willing to contribute to creating a Digital Technologies-empowered ESG. A recent survey by KMPG shows that 74% of technology company CEOs consider it their responsibility to adopt ESG (KPMG, 2020). There are also indications that businesses are not afraid of more regulation aimed at increasing sustainability if this would also increase predictability.

# **SCENARIOS ASSESSMENT** AND CONCLUSIONS

As a well-established practice in the EIT Digital 'Makers and Shapers' report series, we conclude with an assessment of the scenarios using a radar diagram. The dimensions used in the assessment were already mentioned in the storylines and the table below illustrates the meaning of the scores used in the diagram.

| Score | Dimensions | | | | |
|---|---|---|---|---|---|
| | Growth | Energy consumption | Social cohesion | Energy transition | Green innovation |
| 1 | recession | sharp increase | high worsening | stopped | stopped |
| 2 | decrease | increase | worsening | decrease | decrease |
| 3 | slight decrease | slight increase | slightly worsening | slight decrease | slight decrease |
| 4 | stable | stable | stable | stable | stable |
| 5 | slight increase | slight decrease | slight improvement | slight increase | slight increase |
| 6 | increase | decrease | improvement | increase | Increase |
| 7 | high increase | sharp decrease | high improvement | fast transition | high increase |

**Table 2** Radar diagram dimensions and scoring

For ease of reference the table above reports the actual score per dimension per scenario. The storylines are already quite clear on the various dimensions and the scoring self-explanatory, hence, below we only add a few illustrative comments.

In the Compensation scenario, economic growth is partly constrained due to increasing energy intensity of digital technologies with effect on other sectors, energy consumption is stable, but energy transition hampered. Green innovation increases in most sectors, but not in digital technologies which will influence the total. Social cohesion may slightly worsen. The digital exception could develop out of control, slowing down overall green innovation more.

In the Utopia scenario, economic growth may be further constrained but stimulated through focused measures for innovation, high energy efficiency and effective energy transition. The issue of energy prices and their short-term effect on social cohesion may be more problematic but is compensated by more confidence in attacking climate change, hence avoiding climate disasters and proving a safer life. This scenario maximises green innovation.

In the Deprivation scenario, there is only mild impact on economic growth, and social cohesion in the short term is stable but less in the longer term due to climate change. On the other hand, because of limited interventions, the positive impacts on energy consumption and transition, as well as green innovation are very limited because the rigidities of other sectors of economy offset the positive contribution of the digital sector.

The Dystopia scenario is self-explanatory, unfettered growth generates dissipation and entropy, with neither green innovation nor energy transition. Social cohesion in the short-term increases, but this may be radically reversed when the effects of increased pollution and climate change sets in.

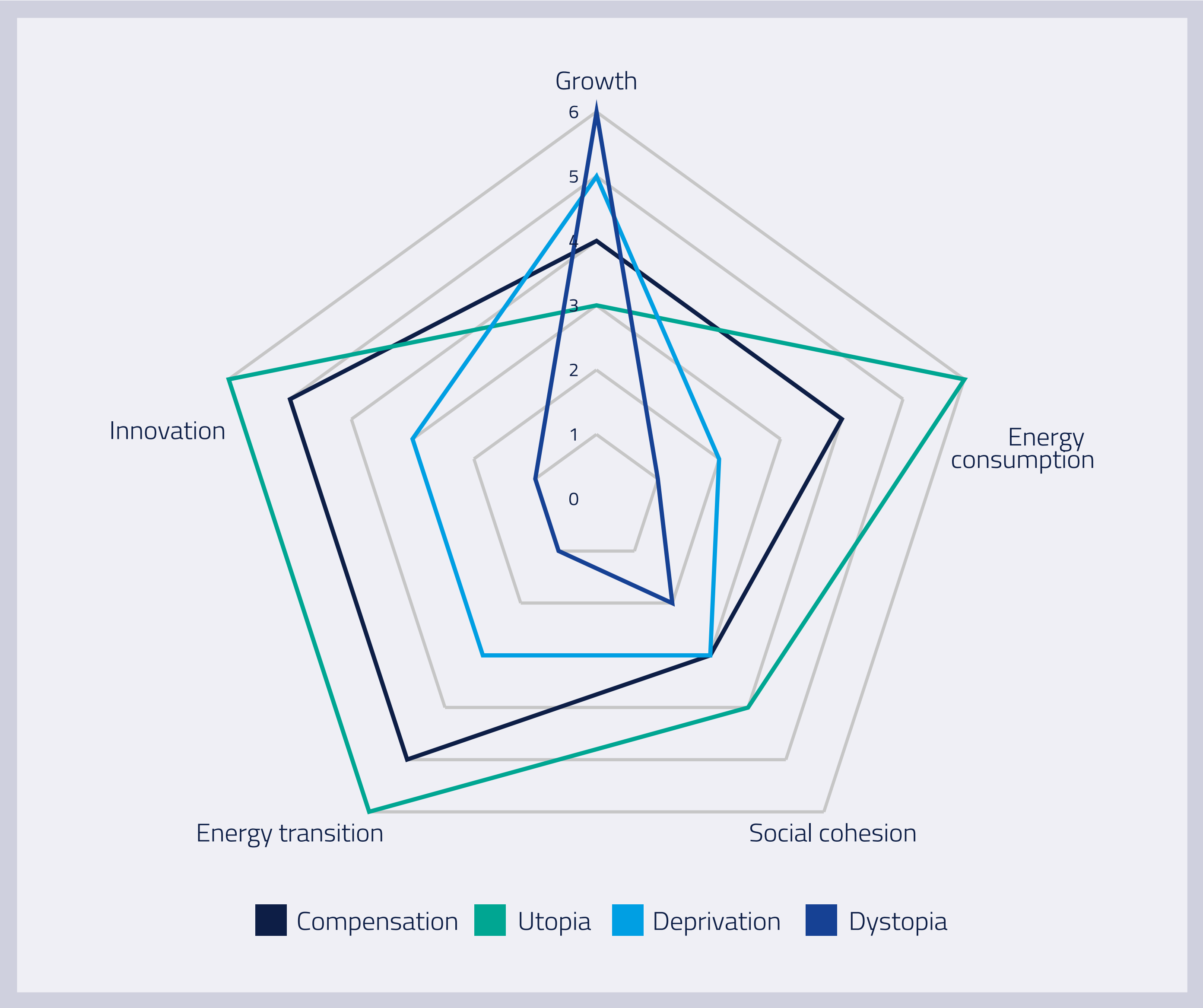



**Figure 3** Radar diagram assessment: objective dimensions. Source: Own elaboration

# CONCLUSIONS

1. The lack of an agreed framework for measuring and modelling digital impact on energy consumption in various sectors leads to many opposing views. To have a fact-based discussion, an agreed framework should be put in place based on international standards to model and quantify the impact of digital technology on energy consumption in various economy sectors.

2. Although a reduction of energy consumption of digital technologies is relevant and should be pursued, the energy consumption of digital tech counts for less than 10% of the total energy consumption.

3. The impact of the application of digital technology on energy consumption varies strongly across economic sectors. Therefore, the focus should be on those sectors where the potential gain is high. For example, the COVID pandemic showed that moving physical meetings online leads to significantly less travel resulting in substantially reduced energy consumption.

4. When applying digital technology in specific sectors, attention must be paid to possible rebound effects, whereby energy savings achieved in one domain are offset by increased use of energy in another domain. These are linked to both behavioural (i.e., consumers' substitution waves) and structural factors (i.e., energy output elasticity of certain sectors) that can be contained only through strong interventions such as taxation and incentives.

# ACKNOWLEDGEMENTS

This report on Digital Technologies and the Green Economy is part of the EIT Digital Makers & Shapers report series. These reports address specific aspects of digital technologies and developments. They follow a scenario-based approach, grounded on the developments and state of the art in the specific field, and analyse the impact of the different scenarios on specific predefined indicators. The report on Digital Technologies and the Green Economy assesses in particular the role that Digital Technologies can play in achieving climate goals.

Digital Enlightenment Forum was contracted to support the study and write this report under the guidance and supervision of EIT Digital. We acknowledge the contribution of the Digital Enlightenment Forum by providing breadth and depth to the study via interdisciplinary stakeholder discussions, as well as extensive literature analysis and survey. Special thanks go to Jacques Bus, George Metakides and Cristiano Codagnone.

*Brussels, February 2022*

# REFERENCES

Andrae, A. S. (2019). Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030. Preprint, 1-23.

Andrae, A. S., & Edler, T. (2015). On global electricity usage of communication technology: trends to 2030. Challenges, 6(1), 117-157.

Ayres, R.U., Warr, B., (2009). The economic growth engine: how energy and work drive material prosperity. Cheltenham: Edward Elgar.

Aslan, J., Mayers, K., Koomey, J. G., France, C. (2018). Electricity intensity of Internet data transmission: Untangling the estimates. Journal of Industrial Ecology, 22(4), 785-798.

Berkhout, F., Hertin, J., (2001). Impacts of Information and Communication Technologies on Environmental Sustainability: speculations and evidence. report to the OECD. Falmer: SPRU.

Bieser, J. C., & Hilty, L. M. (2018). Assessing indirect environmental effects of information and communication technology (DIGITAL TECHNOLOGIES): A systematic literature review. Sustainability, 10(8), 2662.

Buchanan, K., Russo, R., Anderson, B. (2015). The question of energy reduction: The problem(s) with feedback. Energy Policy, 77, 89–96.

Caviglia-Harris, J., Chambers, D., Kahn, J. (2009). Taking the 'U' out of Kuznets. Ecological Economics, 68, 1149–1159.

CISCO. (2019). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022.

Corcoran, P., & Andrae, A. (2013). Emerging trends in electricity consumption for consumer DIGITAL TECHNOLOGIES. Galway: National University of Ireland.

Coroama, V. C., Hilty, L. M., Birtel, M. (2012). Effects of Internet-based multiple-site conferences on greenhouse gas emissions. Telematics and Informatics, 29(4), 362-374.

Coroama, V. C., Hilty, L. M., Heiri, E., Horn, F. M. (2013). The direct energy demand of internet data flows. Journal of Industrial Ecology, 17(5), 680-688.

Coroama, V.C., Hilty, L.M., (2014). Assessing Internet energy intensity: A review of methods and results. Environmental Impact Assessment Review, 45, 63–68.

Council of the European Union. (2020). Draft Council Conclusions on Making the Recovery Circular and Green. Brussels: Council of the European Union.

Davis, J., Edgar, T., Graybill, R., Korambath, P., Schott, B., Swink, D., Wetzel, J. (2015). Smart manufacturing. Annual review of chemical and biomolecular engineering,6, 141-160.

Digital Europe. (2021). Digital Action, Climate Action. 8 Ideas to Accelerate the Twin Transition. Brussels: Digital Europe ( https://www.digitaleurope.org/wp/wp-content/uploads/2021/10/DIGITALEUROPE_Digital-action-Climate-action.pdf , accessed 13/11/2021).

European Commission. (2020a). Shaping Europe's digital future. COM(2020) 67 final, Brussels.

European Commission. (2020b). Consumer policy – strengthening the role of consumers in the green transition. Inception Impact Assessment (Ares(2020)3256804), retrieved from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12467-Consumer-policy-strengthening-the-role-of-consumers-in-the-green-transition_en ( 16 August 2021).

European Commission. (2020cb). A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM(2020) 98 final, Brussels.

European Commission. (2020d). Strengthening consumer resilience for sustainable recovery. COM(2020) 696 final, Brussels.

European Commission. (2020e). Sustainable Product Initiative. Inception impact assessment (Ares(2020)4754440)

European Parliament and Council. (2006). Concerning the Registration, Evaluation, Authorisation and RestrDigital Technologiesion of Chemicals (REACH). Regulation (EU) 1907/2006.

European Parliament and Council. (2009). Establishing a framework for the setting of ecodesign requirements for energy-related products. Directive 2009/125/EC.

European Parliament and Council. (2012). On waste electrical and electronic equipment (WEEE). Directive 2012/19/EU.

European Parliament and Council. (2017a). Amending Directive 2011/65/EU on the restrDigital Technologiesion of the use of certain hazardous substances in electrical and electronic equipment. Directive 2017/2102/EU.

European Parliament and Council. (2017b). Setting a framework for energy labelling and repealing Directive 2010/30/EU. Regulation (EU) 2017/1369.

European Parliament and Council. (2018). Amending Directive 94/62/EC on packaging and packaging waste. Directive 2018/852/EU.

Eurostat. (2021). DIGITAL TECHNOLOGIES sector - value added, employment and R&D - Statistics Explained (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=DIGITAL TECHNOLOGIES_sector_-_value_added,_employment_and_R%26D , accessed 22/10/2021).

Eurostat. (2021). National accounts and GDP: Gross value added in the EU by economic activity - Statistics Explained ( https://ec.europa.eu/eurostat/statistics-explained/index.php?title=National_accounts_and_GDP , accessed 22/10/2021).

GeSI & Accenture, (2015). Smarter 2030. DIGITAL TECHNOLOGIES Solutions for 21st Century Challenges. Brussels.

GeSI &Deloitte, (2019). Digital with Purpose: Delivering a SMARTer2030. Brussels.

Gossart, C. (2015). Rebound effects and DIGITAL TECHNOLOGIES: a review of the literature. DIGITAL TECHNOLOGIES innovations for sustainability, 435-448.

Hilty, L. M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., Wäger, P. A. (2006). The relevance of information and communication technologies for environmental sustainability–a prospective simulation study. Environmental Modelling & Software, 21(11), 1618-1629.

Hilty, L. M., Coroama, V., De Eicker, M. O., Ruddy, T., Müller, E. (2009). The role of DIGITAL TECHNOLOGIES in energy consumption and energy efficiency. Report to the European Commission, DG INFSO, Project DIGITAL TECHNOLOGIES ENSURE.

Horner, N. C., Shehabi, A., Azevedo, I. L. (2016). Known unknowns: Indirect energy effects of information and communication technology. Environmental Research Letters, 11(10), 103001.

IPCC. (2018). Global warming of 1.5 C. Geneva: IPCC (https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf, accessed 22/10/2021).

Jenkins, J., Nordhaus, T., Shellenberger, M., (2011). Energy emergence: rebound and backfire as emergent phenomena. Oakland: Breakthrough Institute.

Jensen, T., Holtz, G., Baedeker, C., Chappin, É.J. (2016). Energy-efficiency impacts of an air-quality feedback device in residential buildings: An agent-based modeling assessment. Energy and Buildings, 116, 151–163.

Koomey, J., Berard, S., Sanchez, M., Wong, H., (2011). Implications of historical trends in the electrical efficiency of computing. IEEE Annals of the History of Computing, 33, pp. 46–54

Koomey, J. G., Scott Matthews, H., Williams, E. (2013). Smart everything: Will intelligent systems reduce resource use? Annual Review of Environment and Resources,38, 311-343.

Koot, M., & Wijnhoven, F. (2021). Usage impact on data center electricity needs: A system dynamic forecasting model. Applied Energy, 291, 116798.

KPMG. (2020). The ESG Imperative for Technology Companies (https://assets.kpmg/content/dam/kpmg/us/pdf/2020/04/esg-imperative-for-tech-companies.pdf, accessed 24/10/2020)

Lange, S., Pohl, J., Santarius, T. (2020). Digitalization and energy consumption. Does DIGITAL TECHNOLOGIES reduce energy demand? Ecological Economics, 176, 106760.

Lange, S., Pütz, P., Kopp, T. (2018). Do Mature Economies Grow Exponentially? Ecological Economics, 147, 123–133.

Lange, S., Santarius, T. (2020). Smart Green World? Making Digitalization Work for Sustainability. Abington: Routledge.

Malmodin, J. & Coroama, V. (2016). Assessing DIGITAL TECHNOLOGIES's enabling effect through case study extrapolation — The example of smart metering. Presented at the 2016 Electronics Goes Green 2016+ (EGG). IEEE, Berlin, pp. 1–9.

Malmodin, J., & Lundén, D. (2018). The energy and carbon footprint of the global DIGITAL TECHNOLOGIES and E&M sectors 2010–2015. Sustainability, 10(9), 3027.

Masanet, E., Shehabi, A., Lei, N., Smith, S., Koomey, J., (2020). Recalibrating global data center energy-use estimates. Science, 367, 984–986.

Meyers, R. J., Williams, E. D., Matthews, H. S. (2010). Scoping the potential of monitoring and control technologies to reduce energy use in homes. Energy and buildings, 42(5), 563-569.

Mickoleit, A., 2010. Greener and Smarter: DIGITAL TECHNOLOGIESs, the Environment and Climate Change (OECD Green Growth Papers No. 2010/01). Paris: OECD publishing.

Mora, C., Rollins, R. L., Taladay, K., Kantar, M. B., Chock, M. K., Shimada, M., Franklin, E. C. (2018). Bitcoin emissions alone could push global warming above 2 C. Nature Climate Change, 8(11), 931-933.

Mulder, P., de Groot, H.L.F., Pfeiffer, B. (2014). Dynamics and determinants of energy intensity in the service sector: A cross-country analysis, 1980–2005. Ecological Economics, 100, 1–15.

Nadel, S., (2012). The Rebound Effect: Large or Small? American Council for an Energy- Efficient Economy.

Nilsson, A., Wester, M., Lazarevic, D., Brandt, N., (2018). Smart homes, home energy management systems and real-time feedback: Lessons for influencing household energy consumption from a Swedish field study. Energy and Buildings, 179, 15–25.

OECD. (2015). Digital Economy Outlook 2015. Paris: OECD publishing.

OECD. (2017). OECD Digital Economy Outlook 2017. Paris: OECD Publishing.

OECD. (2019). Measuring the Digital Transformation - A Roadmap for the Future. Paris: OECD Publishing.

Potočnik, J. (2019). Digital 4 Planet. When Digital Meets Circular. Digital Assembly 2019, Bucharest 13-14 June.

Salahuddin, M., & Alam, K. (2015). Internet usage, electricity consumption and economic growth in Australia: A time series evidence. Telematics and Informatics, 32(4), 862-878.

Salahuddin, M., & Alam, K. (2016). Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis. International Journal of Electrical Power & Energy Systems, 76, 185-193.

Santarius, T., (2014). Der Rebound-Effekt: ein blinder Fleck der sozial-ökologischen Gesellschaftstransformation. GAIA - Ecological Perspectives for Science and Society, 23, 109–117.

Santarius, T., Walnum, H.J., Aall, C. (Eds.), 2016. Rethinking Climate and Energy Policies: New Perspectives on the Rebound Phenomenon. Cham: Springer International Publishing.

Sedlmeir, J., Buhl, H., Fridgen, G. et al. (2020). The Energy Consumption of Blockchain Technology: Beyond Myth. Bus Inf Syst Eng, 62, 599–608.

Schulte, P., Welsch, H., Rexhäuser, S. (2016). DIGITAL TECHNOLOGIES and the Demand for Energy: Evidence from OECD Countries. Environmental and resource economics, 63(1), 119-146.

Schwartz, R., Dodge, J., Smith, N. A., & Etzioni, O. (2020). Green AI. Communications of the ACM, 63(12), 54-63.

Shehabi, A., Walker, B., Masanet, E., (2014). The energy and greenhouse-gas implications of internet video streaming in the United States. Environ. Res. Lett. 9, 054007.

Shift Project (2019). Lean DIGITAL TECHNOLOGIES: Towards digital sobriety. Paris.

Stern, D. (2004). The rise and fall of the Environmental Kuznets Curve. World Development, 32, 1419–1439.

Strubell, E., Ganesh, A. and McCallum, A. (2019). Energy and policy considerations for deep learning in NLP. In Proceedings of ACL, 2019.

Sui, D. Z., & Rejeski, D. W. (2002). Environmental impacts of the emerging digital economy: the e-for-environment e-commerce? Environmental Management, 29(2), 155-163.

Van Heddeghem, W., Lambert, S., Lannoo, B., Colle, D., Pickavet, M., Demeester, P. (2014). Trends in worldwide DIGITAL TECHNOLOGIES electricity consumption from 2007 to 2012. Computer Communication, 50, 64–76.

World Bank. (2020). World Development Indicators: Structure of output (http://wdi.worldbank.org/table/4.2#, accessed 22/10/2021).

Yandle, B., Vijayaraghavan, M., Bhattarai, M., 2002. The Environmental Kuznets Curve: A primer. The Property and Environment Research Center Study, 2, 1–24.

**Publisher**
EIT Digital
Rue Guimard 7
1040 Brussels
Belgium
www.eitdigital.eu

**Contact**
info@eitdigital.eu

**ISBN 978-91-87253-66-9**

Co-funded by the European Union