IMPLEMENT
CONSULTING GROUP_

2022

DIGITAL DECARBONISATION

How the digital sector is supporting climate action

An Implement Consulting Group study commissioned by Google

Tech and climate change report
2022

This report gives an up-to-date overview of how digital technologies and cloud solutions for businesses enable and accelerate the green transition across the economy and society.

Of all the important environmental objectives, this report will mainly focus on the role of digital technology in relation to climate change mitigation. It also presents progress to date towards a carbon-free and environmentally sustainable tech sector.

The report identifies a number of central policy dialogues which are crucial to the achievement of key environmental objective and where a partnership between the tech sector and its stakeholders could possibly bring unique solutions to key environmental challenges.

The report invites a conversation around how digital technologies can accelerate the green transformation in Europe and thereby contribute to key short-term and long-term policy objectives.

Commissioned by

Table of contents

Executive Summary 4

CHAPTER 1: Introduction 8

1.1. The energy and climate crises and digital tech's contribution 8
1.2. Six environmental objectives 9
1.3. The digital technology sector 9
1.4. Digital technology as a sustainable economic activity 10
1.5. Contributing to climate mitigation 11
1.6. Contributing to other environmental objectives 14
1.7. The energy use and carbon emissions from the digital sector 15

CHAPTER 2: Digital decarbonisation 20

2.1. EU carbon emissions are falling, but not fast enough 20
2.2. Decarbonisation happens faster in the most digitalised economies 21
2.3. Digital decarbonisation happens across all major sectors 23
2.4. Use cases show the potential of digital solutions 24
2.5. Approach to assessing the enabling role of digital technologies 25
2.6. Overview of the results 26
2.7. Electrification, renewables and demand flexibility 26
2.8. Transport and digitally enabled climate mitigation 29
2.9. Buildings and digitally enabled climate mitigation 33
2.10. Manufacturing and digitally enabled climate mitigation 36
2.11. Agriculture and digitally enabled climate mitigation 38
2.12. Trade and digitally enabled climate mitigation 39

CHAPTER 3: Decarbonising digital 44

3.1. The tech sector is driving the transition towards zero carbon 44
3.2. Energy efficiency boost from shifts to cloud and hyper scale 48
3.3. Carbon-free electricity building on long experience 52
3.4. Carbon neutral supply chains is the next step 56

CHAPTER 4: Unlocking the potential 59

Detailed collection of use cases 68

Glossary 88

Endnotes 89

EXECUTIVE SUMMARY

Digital solutions are important enablers of affordable and cost-effective climate change mitigation at scale.

For example, digital solutions are a critical enabler of demand flexibility for the forthcoming doubling of electricity use in Europe towards 2050.
The provision of real-time data to support climate-friendly transport choices, or a more climate-conscious heating behaviour in people's homes is a cost-effective way of decarbonising. So is the use of video conferencing when it can replace the need for long business flights as one example.

The enabling potential of digital technology is vast. Digital technology is a general purpose technology, and innovative digital solutions will transcend climate change solutions in countless and unimaginable ways. This report identifies some of these.

The findings

The report aims to identify digital solutions that are already in use in areas with the highest potential for near-term impact on emission reductions and energy savings.

The report finds:

- **Four main sectors** which account for two-thirds of EU's total GHG emissions and **hold significant potential for digitally enabled climate mitigation and energy savings.** These are: transportation, buildings, manufacturing and agriculture.

- In total, **20–25% of the GHG reductions needed for a net-zero EU economy will require some degree of digital enablement** to happen at scale and at an acceptable social cost. This equates to GHG reductions in the EU of 700–900 $MtCO_2e$.

  - *Electrification* is the key decarbonisation pathway, and GHG reductions of around 350–450 $MtCO_2e$ across various sectors depend on a degree of digital enablement. Several digital solutions are already in use in this context, but the uptake is well below the potential.

  - *Energy efficiency* is the second decarbonisation pathway and GHG reductions of around 250–300 $MtCO_2e$ across sectors depend on a degree of digital enablement. A number of digital solutions are already increasing efficiency, but uptake is in the early phase.

  - *Digital displacement* is the third but less potent decarbonisation pathway. A smaller amount of GHG reductions can be enabled by digital solutions replacing less sustainable activities, for example when video conferencing replaces the need for business flights.

  - *Energy security measures* to reduce the EU's imports of fossil fuels also depend on digital solutions. Around 40% of the pathway to the desired level of EU gas demand will require a degree of digital enablement.

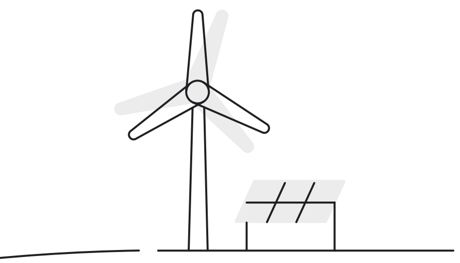
- At the macro level, we find that **decarbonisation happens faster in the most digitalised economies.** Europe's most advanced digital economies reduced their GHG by 25% between 2003 and 2019 and grew their economies by 30% in the same period. Europe's least digital economies also reduced their GHG in that period, but only by 18% while growing their economies by 18%.

- **The potential for digitally enabled decarbonization is significant in comparison with the emissions from the digital value chain.** Data centres in the EU are estimated to account for 15–20 $MtCO_2e$ in 2020 through their operational emissions. It is important to also address the emissions across the whole value chain, including those related to data networks and the end-user devices, as well as embedded emissions.

  - Leading data centre operators such as Microsoft, Iron Mountain and Google are aiming to run on 24/7 carbon-free electricity by 2030, meaning they will match their consumption hour-by-hour with carbon-free energy from the grid where they operate.

  - Three of Google's five European data centres already operate at more than 80% carbon-free electricity (namely in Finland, Denmark and Belgium) and two (Finland and Denmark) operate at around 90% carbon-free electricity. This means that these locations are well-advanced towards the 24/7 carbon-free target.

  - The hardest part of the decarbonisation journey is ahead of us, and a lot of effort is still needed before the digital value chain is fully carbon-free.



The recommendations

The twin digital and green transformation is already high on the European policy agenda. The EU Council conclusions of December 2020 on *Digitalisation for the benefit of the environment* emphasised that the digital component will be key in reaching the ambitions of the European Green Deal and the Sustainable Development Goals (SDGs) as set out in the EU digital strategy.

On the backdrop of recent geopolitical events and the energy crisis, the European Commission, in its 2022 Strategic Foresight Report, recommends accelerating both transitions. Several underpinning initiatives are ongoing, including the European Green Digital Coalition which is a collaboration among digital companies led by the Commission.

Based on the findings, we see two equally important priorities to accelerate the twin transition:

- **DIGITAL DECARBONISATION:** Maximising the enabling role of digital technologies by accelerating already available digital solutions at scale within four key sectors of the EU economy.

- **DECARBONISING DIGITAL:** Minimising the carbon emissions across the entire digital value chain by decarbonising all operational electricity emissions, and addressing the emissions related to devices as well as servers and buildings etc.

The **digital decarbonisation** priority is about accelerating the uptake of digital solutions enabling climate change mitigation. This will require an enabling policy framework.

European businesses have more than doubled their use of cloud solutions over the last five years and are demanding green digital solutions to drive their business and growth, but an unfinished policy framework means lost opportunities for financing the development and deployment of green digital solutions. It also means a risk of increasing internal market obstacles and difficulties in procurement of green digital technology solutions. This works against the ambition of an accelerated transition.

The EU policy framework should be strengthened in the short term to provide incentives to invest in cost-effective digital climate solutions and ensure efficient movement of capital within the internal market into the most effective digital climate solutions. This will require:

- An alignment at EU level across the various policy initiatives on the definition of sustainable activities and activities enabling a significant contribution to climate change mitigation. The efforts of the European Green Digital Coalition towards this objective are important.

- Coherence between EU and national policy initiatives towards sustainable digital solutions to avoid barriers to the internal market for technologies enabling substantial contribution to environmental objectives.

- An external EU trade policy which also supports these objectives by promoting trade in digital services with positive enabling effects for the environment.

The report also recommends that the ongoing efforts to decarbonise digital should be accelerated by encouraging a shift toward a 24/7 carbon-free energy approach to addressing operational electricity emissions, as this will most effectively drive decarbonisation in electricity consuming industries. This will among other things require an alignment across EU and national policies around the approach for decarbonising the digital value chain.

The report is structured as follows:

- **CHAPTER 1** provides an introduction to the broader relation between digital technology and environmental objectives.
- **CHAPTER 2** is titled **"Digital Decarbonisation"** and is devoted to the enabling role of digital technology. It contains an outward looking analysis of how digital technologies are contributing to mitigating climate change in other sectors of the economy.
- **CHAPTER 3** is titled **"Decarbonising Digital"** and looks inwards to address the digital value chain and how to mitigate the impact of technology on climate change.
- **CHAPTER 4** unpacks the above policy perspectives following from the analyses.

CHAPTER 1: Introduction

Tech and sustainability

Digital technologies are already contributing substantially and positively to many environmental objectives. Digital technologies can also help solve two of Europe's most pressing policy problems – the energy crisis and the climate crisis.

1.1. The energy and climate crises and digital tech's contribution

Europe is facing both a short-term energy challenge (ending dependence on Russian gas) and a long-term climate challenge (achieving a net-zero economy by 2050). To this end, the European Green Deal and REPowerEU are key instruments for transforming the EU economy, society, and energy system.

Massive investments are needed. More than EUR 560 billion is to be invested in electricity infrastructure alone.[1] Substantial investments are needed in solar panels, 10 million heat pumps in homes, buildings and factories, and getting 30 million zero-emission vehicles on the road by 2030.[2] This will require massive electrification, massive expansion of carbon-free energy sources such as wind and solar, and new investments to produce hydrogen and other sustainable fuels.

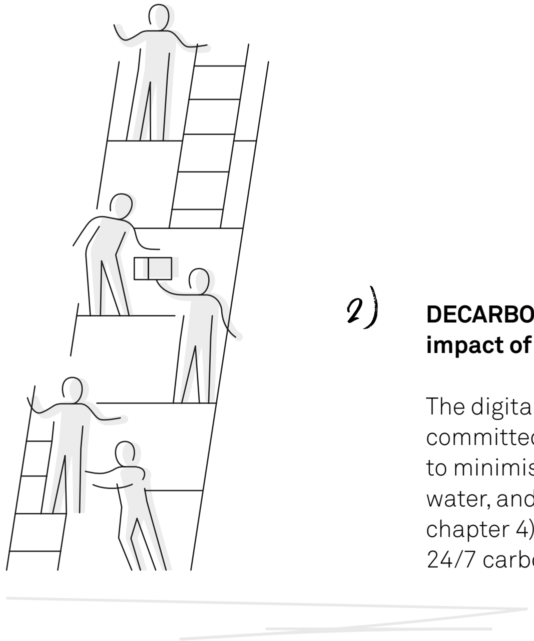
To achieve this level of transformation at speed, it will require an even greater level of collaboration between governments, businesses and citizens.

This transformation can only happen if we can channel capital flows towards the most sustainable investments. To achieve this goal, it is important to fully exploit the potential of the internal market, and the EU Taxonomy firmly states: *"it is crucial to remove obstacles to the efficient movement of capital into sustainable investments in the internal market and to prevent new obstacles from emerging"*.[3]

As we will argue in this report, digital technology is a key enabler of this transformation and the green and digital transformations need to go hand in hand. This leads to two main policy challenges:

1) **DIGITAL DECARBONISATION | How can we maximise the enabling contribution of the digital sector towards a net-zero economy?**

The digital sector is enabling substantial positive environmental outcomes in all other sectors of the economy (see chapter 2). We will need to define sustainable digital solutions and develop policies to ensure that there are no obstacles to the digital sector's contribution to key environmental objectives (see chapter 4).



2) **DECARBONISING DIGITAL | How can we minimise the negative environmental impact of the digital sector and achieve a 24/7 carbon-free digital sector?**

The digital sector itself has reduced emissions significantly, and leading players are committed to becoming 24/7carbon-free by 2030 (see chapter 3). We need to continue to minimise the negative environmental impacts of resource use, including energy, water, and materials, and find policy choices that support this development (see chapter 4). Can we make the EU the first continent to operate all of its data centres on 24/7 carbon-free energy?

In this introduction, we will home in on how to view the relationship between the digital technology sector and the environment and discuss how to define the enabling role of digital technology in relation to key policy objectives.

1.2. Six environmental objectives

This report looks at digital use cases and their potential for meeting six environmental objectives:

- Climate change mitigation
- Climate change adaptation
- Sustainable use and protection of water and marine resources
- Transition to a circular economy
- Pollution prevention and control
- Protection and restoration of biodiversity and ecosystems

Of all the important environmental objectives, this report will focus on the role of digital technology in relation to climate change mitigation (see section 1.5). Digital technology also contributes to the other five environmental objectives (see section 1.6). Finally, the digital industry also uses energy and physical products. Thus, the negative environmental impact of that activity is also considered (see section 1.7 and, in more detail, chapter 3 of the report).

1.3. The digital technology sector

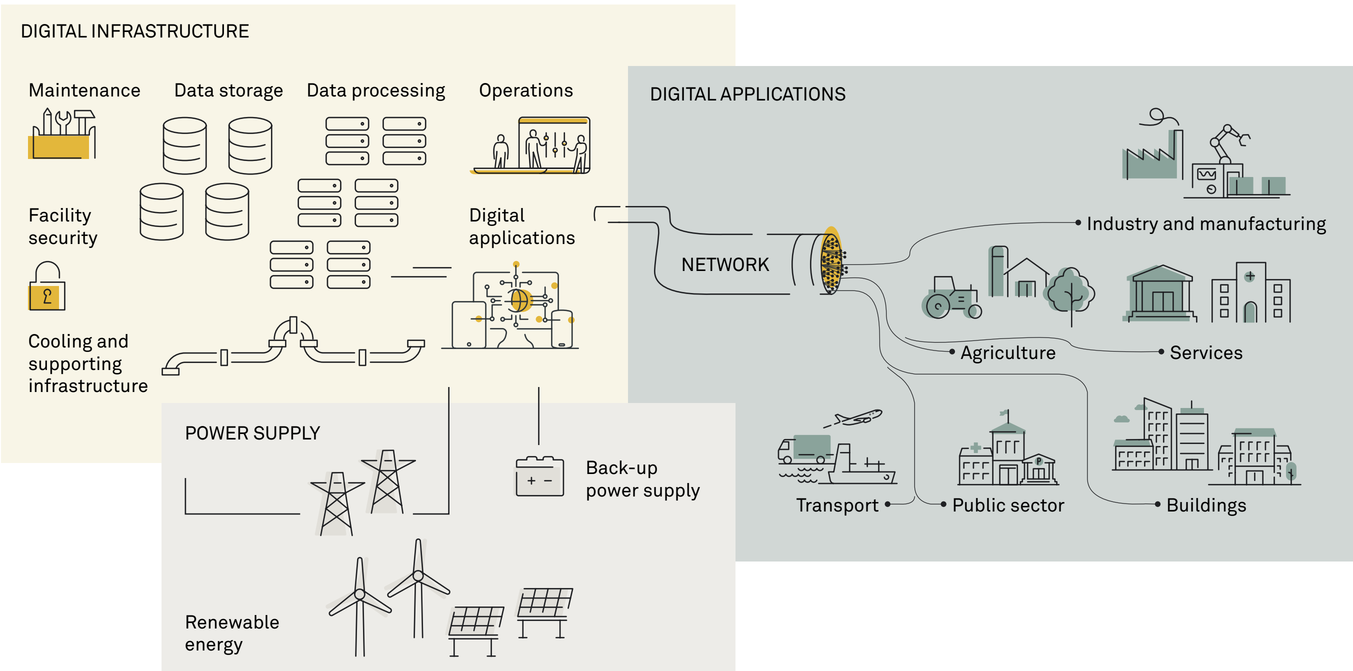
Digital technologies are electronic tools, systems, devices and resources that generate, store or process data.

For the purposes of this report, we define the digital sector as being comprised of data centres, data transmission networks, and user devices that enable the operation and consumption of digital services.

Data centres are only a part of the digital sector. Data centres enable the cloud, which allows our phones, tablets and laptops to run apps. In turn, these apps are used throughout the economy for healthcare, education, business and social engagement via data networks and via devices and terminals at the end-users.

Figure 1.

The tech sector and its users



Note: Implement's own illustration.

1.4. Digital technology as a sustainable economic activity

Digital technology is a general purpose technology.[4] This means that the technology can be used for many purposes, good and bad. This is just the same as the railways, which can be used to transport both oil barrels and wind turbines.

Some applications of digital technology can enable other economic activities to make a substantial contribution to environmental objectives.

When an economic activity (e.g. a certain application of digital technology) directly enables other activities to make a substantial contribution to an environmental objective, that economic activity can be said to contribute substantially to environmental objectives. This follows from the EU Taxonomy.

This does not mean that all applications of digital technology can be seen as contributing substantially to environmental objectives. AI can be used to both reduce carbon emission in buildings, as well as to optimise the extraction of shale gas, which could lead to an increase in carbon emissions.

The production of digital technologies also entails some negative impacts on the environment, and reducing such negative impacts can make a substantial contribution to one or more environmental objectives.[5]

Activities where carbon-free alternatives are not yet technically or economically feasible and which have a substantial enabling effect on other economic activities are defined as transitional economic activities. Those transitional economic activities should qualify as contributing substantially to climate change mitigation if their greenhouse gas emissions are substantially lower than the sector or industry average.[6]

Finally, and following the narrow definition in the EU Taxonomy, an economic activity should only qualify as environmentally sustainable if the harm it does to the environment is outweighed by the benefits it brings.[7] In practice, this assessment can be complex as we will discuss in the next section.

1.5. Contributing to climate mitigation

Digital technologies enable substantial contributions to carbon mitigation across all sectors of the European economy.

There are multiple ways in which digital technologies are supporting the green transition, as is shown in chapter 2 of the report.

1) **DO DIFFERENTLY | Digital technologies enable the transition to non-polluting alternatives**
Digital technologies are a key enabler in the transition to a net-zero society, making renewable energy solutions cost-efficient. An example is smart charging technology[8] that smoothens electricity demand which in turn enables electrification at reasonable costs.

2) **USE LESS | Digital technologies enable reduced use of resources**
… through human action
Digital technologies allow humans to use relevant data to take action towards key sustainability objectives. An example is eco-routing software, which gives drivers the most efficient route to save energy and time, and therefore emissions.

… and through machine action
Digital technologies can automatically act on relevant data through AI/ML technologies towards key sustainability objectives. An example is the optimisation by AI of energy use for heating and cooling in large buildings without compromising comfort.

3) **STOP USING | Digital technologies can provide a greener alternative to products and services**
Digital technologies can replace some products and services, taking pressure off the environment. An example is video conferencing, which reduces the need for travel.

This report takes the principles above to mean that digital technology would qualify as contributing substantially to climate change mitigation, provided that:

- The application reduces more greenhouse gas emissions than it generates, i.e., the benefits it brings to the environment outweigh the harm it does.

- The greenhouse gas emissions from the specific application are substantially lower than the sector or industry average.

On the first criterion, previous reports have shown the potential of digital technologies towards climate mitigation.[9] This report offers an updated perspective, which confirms the vast potential from digital technologies in relation to climate mitigation. In chapter 2 of this report, we provide details of specific use cases which all enable a substantial contribution to climate mitigation in Europe today and which have the potential to contribute substantially to achieving Europe's target of 55% reduction by 2030 and the ambition of carbon-neutrality by 2050.

As for the second criterion, this would require refined industry standards which capture differences between, for example, suppliers in terms of energy efficiency and the related carbon emissions. Such measurements should consider the efforts of leading technology firms to ensure hour-by-hour carbon free energy use, and additional carbon-free energy capacity to local grids. These aspects – as well as the emissions from the supply chain (scope 3) – are discussed in chapter 3.

The main focus for the twin green and digital transition should be on maximising the enabling role of digital technologies and minimising carbon emissions across the entire digital value chain.

Previous reports have suggested that digital technologies can save ten times more emissions than what they generate.[10] This report offers an alternative perspective. There are several reasons why it might be helpful to think a little differently about the ratio of emissions saved to emissions created. While the ratio is conceptually sound, both the denominator and numerator of that equation are hard to determine:

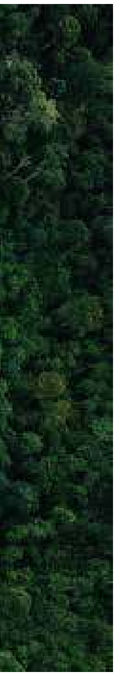
- *First,* the denominator (emissions created) is too narrowly defined if it only accounts for data centre emissions. Digital solutions are delivered via a value chain comprised of not just data centres, but also data networks and devices at the user-end. Furthermore, data centres rely on servers and cooling equipment – both of which also generate emissions both in operation and in their value chains (scope 3).

- *Second,* the numerator (emissions saved) is likely a very big number, which is virtually impossible to define and quantify since digital technology is a general purpose technology with countless applications that often enables the achievement of green transformation together with other technologies. Attributing a portion of emissions saved to the digital part of a large-scale transformation is challenging and almost impossible, since digital solutions are woven into almost any modern transformation solution.

- *Third,* the numerator should not only include the positive impact on the environment. Most reports ignore the environmental impacts of all other digital applications which might be leading to an increase in emissions in other sectors (e.g. ML to support enhanced oil recovery).

- *Fourth,* digital solutions cross geographic borders, just like data centres in one region may run applications that have environmental impacts in many other regions – so c both the impacts and the related emissions is challenging.

- *Finally,* digital solutions are developing fast and will be used in novel ways in the future. Even if a reasonable estimate of the enabled emission reductions was established, it would be outdated very quickly.



For these reasons, it would be very ambitious to calculate the ratio of emissions saved to emissions created for all applications of digital technology combined. All such calculations would come to similar conclusions, namely that the enabled emissions reduction are many times higher than the emissions created, but with large uncertainties in the magnitude of effects (e.g., whether it is a factor five, ten or more).

The central argument is that digital technologies are now in the DNA of nearly every transformation towards the net-zero goal. Digital technologies are essential to EU-wide decarbonization, and therefore the issue is not whether the ratio is 1:5, 1:10 or something bigger, but how we continue to minimise the direct footprint of digital technologies and dramatically increase their enabling contribution to climate change mitigation and other environmental objectives.

The digital sector has been at the forefront of driving the decarbonisation of its operational footprint. While many electricity consuming companies are still relying on carbon-free energy certificates to show climate responsibility, companies like Google, Iron Mountain and Microsoft have been driving real change for many years, through e.g. PPAs, and have now pledged to operate 24/7 carbon-free by 2030. Nonetheless, there is still a long way to go for the sector to become carbon-free across all scopes of emissions. Many data centre operators continue to buy carbon-free energy certificates and operate on the average grid electricity mix, which will not reach zero in the EU until 2035 at the very earliest – and more likely in the 2040s. Consequently, it is important to get all data centre operators on board in raising their ambitions to commit to the target of carbon-free operations.

1.6. Contributing to other environmental objectives

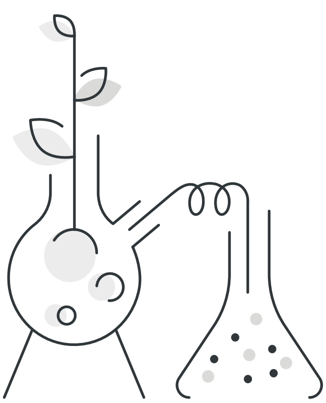
There are also multiple use cases of digital technologies' direct contributions to other environmental objectives:

1.6.1. Climate change adaptation

AI-based flood forecasting system | Machine learning models and artificial intelligence can help assess potential floods, predict the areas that would be affected, and send out warnings to people. The Google Flood Forecasting initiative is doing exactly this. The programme that was started in Bihar, India, uses satellite images to create a model that predicts the water level in a river at any given time, and the areas that are most likely to be hit by floods based on the river's trajectory. Google can then send out warnings to people in the area directly on the phone, up to two days in advance.[11]

Satellite data to monitor the ocean surface | Monitoring the sea level is another important element in climate change adaptation and flood forecasting. For example, NASA uses its satellites and data to provide information on the ocean surface and changing sea levels, making it available publicly.[12]

Using satellites to show real-time wildfire information | Satellites can capture information about the real-time locations and boundaries of wildfires. Google's Crisis Response team developed the Wildfire Boundary Map, which provides real-time information on the location and boundaries of wildfires. This helps people in the area stay safe, supports firefighters in their work, and compiles in one place relevant safety information from local authorities and emergency organisations such as the Red Cross.[13]



1.6.2. Water protection

Mapping and monitoring fresh water supply | Measuring fresh water supply is key for preserving species and adapting to climate change. However, this is a challenge for many countries, with policymakers facing difficulty in designing and monitoring policy objectives in this area. Digital technologies can help by collecting and displaying relevant and accurate data in order to monitor fresh water supply. Google has been collaborating thus with the European Commission's Joint Research Centre (JRC) and United Nations Environment, creating the Freshwater Ecosystems Explorer, an app that provides statistics for every country's annual surface water and shows changes throughout the years through interactive maps, graphs and full-data downloads.[14] NASA has a programme to monitor water changes, underground water loss and droughts.[15]

1.6.3. Biodiversity and ecosystems

Preserving biodiversity | Climate change is affecting the habitat of many species, causing them to migrate and shift their ranges. Digital technologies can use supercomputers and GIS-based mapping tools to help predict where species are moving. The Spatial Planning for Area Conservation in Response to Climate Change (SPARC) tool is building a global picture of the movements made by all known plants, birds and mammals in response to climate change. This can help governments predict where climate change will affect species and plan a habitat conservation response.[16]

Fighting deforestation | Satellite and cloud computing can create high-resolution land surface maps that enable forest monitoring. Google Engine and Google Earth have developed a living map of forests and, in partnership with Global Forest Watch (GFW), made it available to anyone to visualise forest cover and forest change and deforestation.[17] To fight deforestation in businesses' value chain, Google Cloud is partnering with multinationals like Unilever to help them monitor their supply chain and sourcing of raw materials.[18] Digital technologies can also empower indigenous communities to fight illegal logging. Indigenous people in the Amazon can use recycled Android phones and machine learning to detect illegal logging. The phones are connected to solar panels for energy and external microphones to hear the sound of illegal logging. Machine learning analyses the audio to detect the sound of chainsaws and logging trucks and send signals to the rangers.[19]

1.6.4. Circularity

Digital platforms enabling circularity | Digital technologies can support the circular use of materials by sharing relevant information and facilitating the exchange of information and materials between different stakeholders. For example, the Danish government's digital strategy includes the establishment of a circular data bank that collects and disperses data on waste and materials so companies and public authorities can make their material consumption more efficient and less wasteful.[20] Materiom is an example of an open access platform that supports companies, cities, and communities in creating and selecting materials sourced from locally abundant biomass, like agricultural waste, that are part of a regenerative circular economy.[21, 22]

1.7. The energy use and carbon emissions from the digital sector

For the purposes of this report, we define the digital sector as being comprised of data centres, transmission networks, and user devices that enable the operation and consumption of digital services.

Data centres and data transmission networks that enable digitalisation accounted for approximately 300 $MtCO_2e$ on a global scale in 2020 (including embodied emissions) – equivalent to 0.6% of total global GHG emissions.[23] Since 2010, emissions have grown modestly despite rapidly growing demand for digital services. This is due to energy efficiency improvements, carbon-free energy purchases by tech companies, and the ongoing decarbonisation of electricity grids in many regions. Data centres account for approximately half of this footprint.[24] They are estimated to consume 1–1.5% of global electricity[25] and generate around 0.3% of global GHG emissions.[26]

Despite data centres' relatively small contribution to overall emissions, significant efforts have been and continue to be made by owners and operators of data centres to minimise their footprint.

Against this background, a thorough assessment of the environmental impact of digital technologies should comprise of:

- **Data centres and their energy consumption and efficiency**
  Digital technologies need electricity to function. Between 2015 and 2021, the global data centre workloads doubled, while electricity consumption increased much more modestly, thanks to a shift to energy-efficient hyperscale data centres and cloud solutions.

- **Data centres and the decarbonisation of electricity**
  Leading hyperscale data centres are demanding carbon-free electricity and contributing to its development. The global data centre operators have been at the forefront of large-scale renewable energy purchases and are now leading the way towards 24/7 carbon-free electricity use. That means purchasing enough local clean energy to match electricity demand every hour of every day.

- **Data centres and scope 3 emissions**
  Data centres are large buildings filled with servers, cables and cooling equipment. Data centres are major buyers of such equipment, and leading operators can accelerate sustainability among their suppliers via their purchases and policies.

These aspects are discussed in more detail in chapter 3 of this report.

Digital solutions are not only consuming electricity on the data centre side. An assessment of the environmental impacts should also include the broader network and devices.

- **Networks and devices/terminals on the user side**
  Data centres would not be particularly useful without users being able to connect devices and computers at the other end via a network connection. These networks and devices and their environmental footprint – although outside the control of data centre operators – belongs to a full-fledged assessment of the environmental impact of digital technologies.

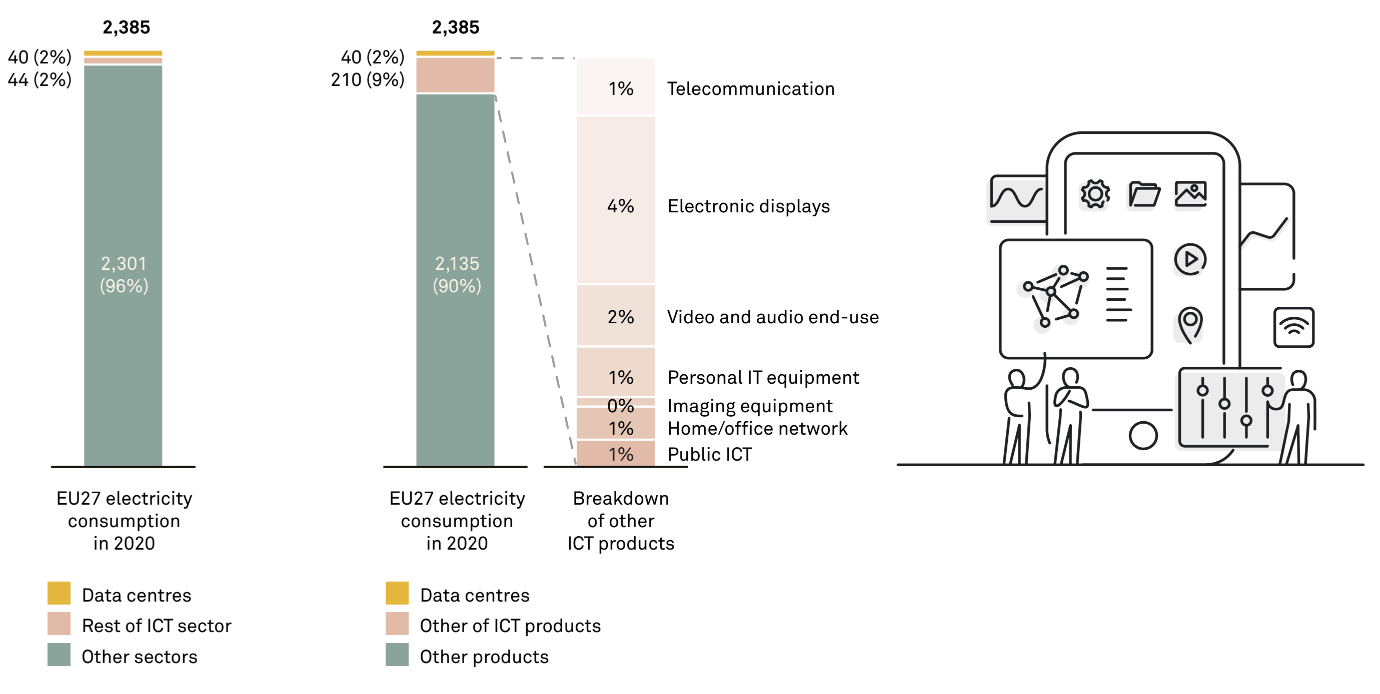
The IEA data does not distinguish device use for digital services and other uses, such as television and gaming, however these can be viewed from an ICT industry perspective and from an ICT products perspective.

- **ICT industry perspective:** The companies registered in the broad ICT industry account for around 4% of total electricity consumption, following the standard Eurostat approach.[27] This includes data centres, which consumed around 1–2% of total electricity in the EU27 in 2020.[28]

- **ICT product perspective:** In an alternative approach, recent research estimated that ICT products, a category which includes televisions and radios, across all industries and in private homes, consume approximately 10% of all electricity in the EU27.[29] Televisions and other displays accounted for 4% of the total.[30] These figures are largely in line with a report on the footprint of ICT in France compiled by two French government agencies.[31]

Figure 2.

EU27 electricty use, 2020
TWh

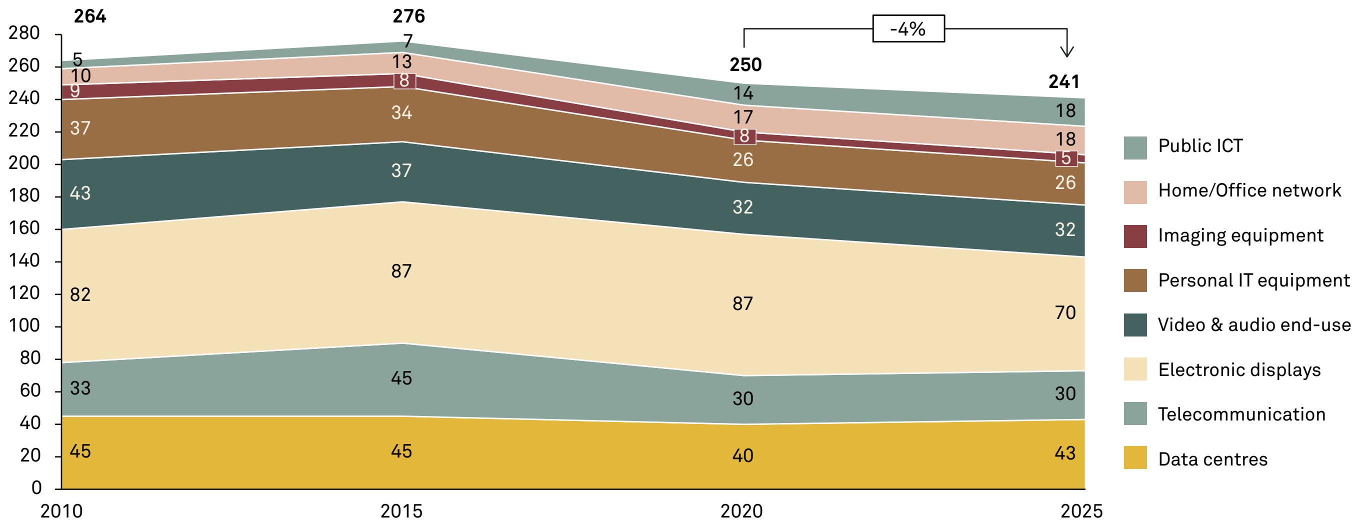


Note: Implement's analysis based on "ICT Impact Study" report.

Electricity consumption of ICT products in the EU27 is projected to fall by 4% between 2020 and 2025 due to energy efficiency gains.

Figure 3.

Electricity consumption by ICT products in the EU27
TWh



Note: Figure reproduced from "ICT Impact Study" report.

In addition to the above aspects, a sustainable tech sector should also be addressing potential positive solutions related to the sustainable use and reuse of water and heat from data centres.

- **Data centres and the reuse of heat**
  Data centres generate heat, and the excess heat can be an input for heating homes and buildings in locations with district heating or industrial heat networks. In this way, data centres can enter into a circular economy with its local community in locations with a municipal infrastructure in place.

- **Data centres and water resource use**
  Data centres use water and air for cooling. Some use water for cooling while others avoid using water at all. Depending on local conditions, using water can be a more energy efficient solution. Assessment of the environmental impact of data centres should consider how much water is used, reused and replenished, and the impact it has on energy efficiency. Some operators are setting targets to replenish more water than they use.

CHAPTER 2: Digital decarbonisation

The role of technology in climate change mitigation

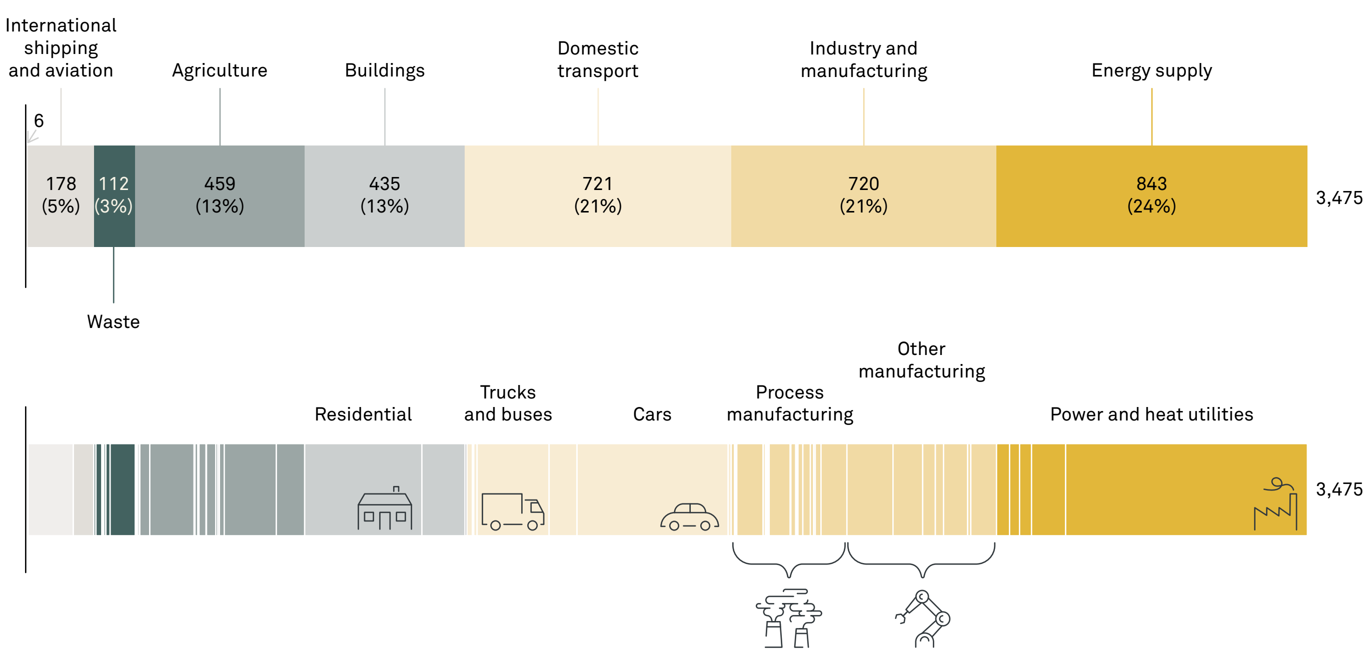
This section gives an up-to-date overview of how digital technologies can enable and accelerate the transition towards a net-zero economy in Europe following the Green Deal agenda and achieving the Fit for 55 target.

2.1. EU carbon emissions are falling, but not fast enough

Digital technology is a critical enabler of reducing the EU's greenhouse gas emissions, which amounted to 3,500 $MtCO_2e$ in 2020, or around 7% of global emissions.[32] The largest emitting sectors are transport (21% of total), buildings (13%), manufacturing (21%) and power (24%).

Figure 4.

Greenhouse gas emissions EU27, 2020
$MtCO_2e$



Note: Data on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States). This data set reflects the GHG inventory data for 2022 as reported under the United Nations Framework Convention for Climate Change. CRF inventory categories: Energy supply: CRF 1A1 (energy industries) + 1B (fugitives); Industry: CRF 1A2 (manufacturing industries and construction) + CRF 2 (industrial processes and product use); Domestic transport: CRF 1.A.3; Residential and commercial: CRF 1A4a (commercial) + CRF 1A4b (residential); Agriculture: CRF 1A4c (agriculture, forestry and fishing) + CRF 3 (agriculture); Waste: CRF 5 (waste); LULUCF: CRF 4 (LULUCF); International aviation (CRF 1D1a); International shipping (CRF 1D1b); Other combustion (CRF1A5a + CRF1A5b + CRF indirect CO2). Data from the EEA.

The EU has set a target of a net 55% reduction in greenhouse gas emissions by 2030 (relative to the 1990 level) and to become carbon neutral by 2050.[33] By 2020, the net reduction was 34% relative to 1990 and with known measures, the European Environment Agency assesses that a 41% net reduction will be achieved by 2030.

This means that more effective policies and measures will be needed to bring the 55% target within reach.[34] The decarbonisation process will need to accelerate.

2.2. Decarbonisation happens faster in the most digitalised economies

The EU economy has already begun decoupling greenhouse gas emissions from economic growth. This decoupling started around 2003. During the same period, the EU saw an increased use of digital solutions and the emergence of cloud solutions, but the causal relationship between the two is yet to be explored.

Digital technologies are enabling decarbonisation at reasonable costs. Digitalisation also enables economic growth that is far less harmful to the environment.

The development since 2003 shows that while decarbonisation is widespread among all EU economies, the ongoing decarbonisation happens faster in the most digitalised economies.

Europe's most advanced digital economies (as ranked by the score on the DESI-index[35]) successfully reduced greenhouse gas emissions by 25% between 2003 and 2019 (and by 33% if taking 2020 into account). During the same period, the most advanced digital countries grew their economies by 30% in real terms.

Europe's least digitised economies also achieved a reduction in greenhouse gas emissions after 2003. Greenhouse gas emissions in these countries dropped by 18% between 2003 and 2019, while their economies grew by 18%.

As we will show in this part, digital consumer applications and cloud-based solutions to businesses and the public sector are already playing an important role across all major parts of our economies and contributing to the ongoing decoupling of economic growth from impacts on the climate. As is also apparent, much more needs to be done to reduce the pressure on the climate to a sustainable level and meet the interim targets in 2030 and to achieve the net-zero goal by 2050.

Figure 5.

Digitalisation is correlated with a higher degree of decoupling between economic growth and emissions

Most advanced digital economies in the EU

-25% reduction in greenhouse gas emissions between 2003 and 2019

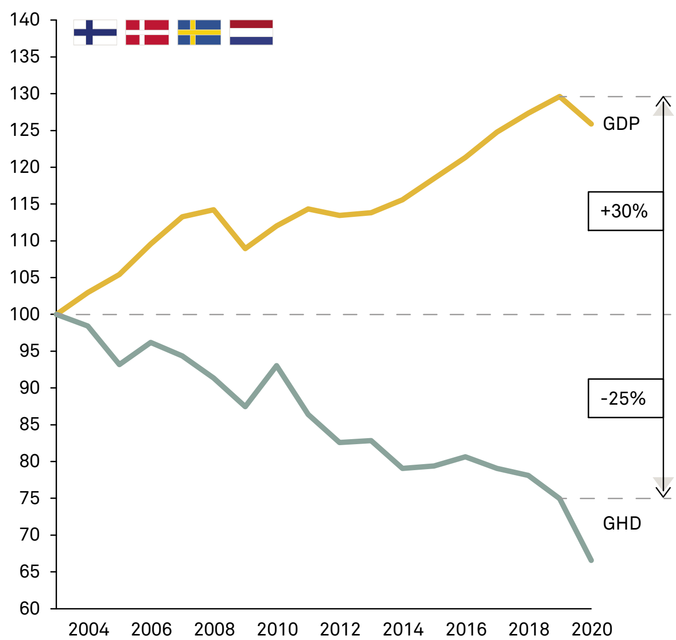
+30% increase in economic output (GDP) in the same period

Least advanced digital economies in the EU

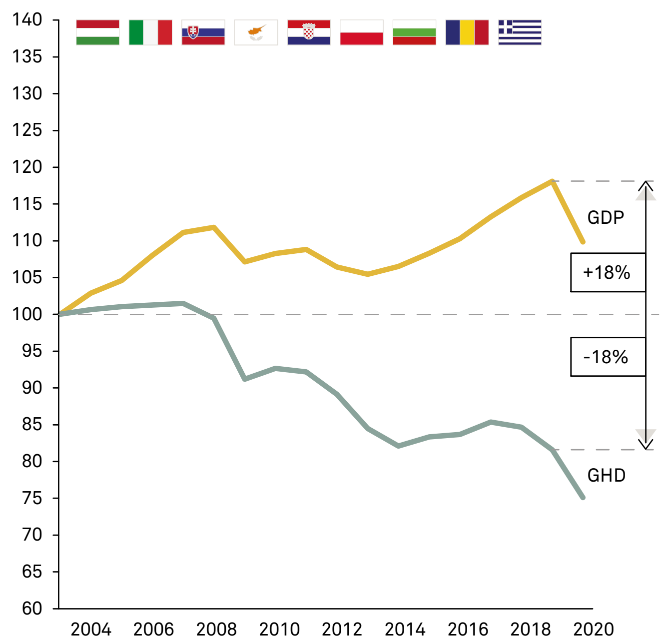
-18% reduction in greenhouse gas emissions between 2003 and 2019

+18% increase in economic output (GDP) in the same period

Economic output (GDP) and greenhouse gas emissions (GHG)
Index 2003 = 100



Economic output (GDP) and greenhouse gas emissions (GHG)
Index 2003 = 100



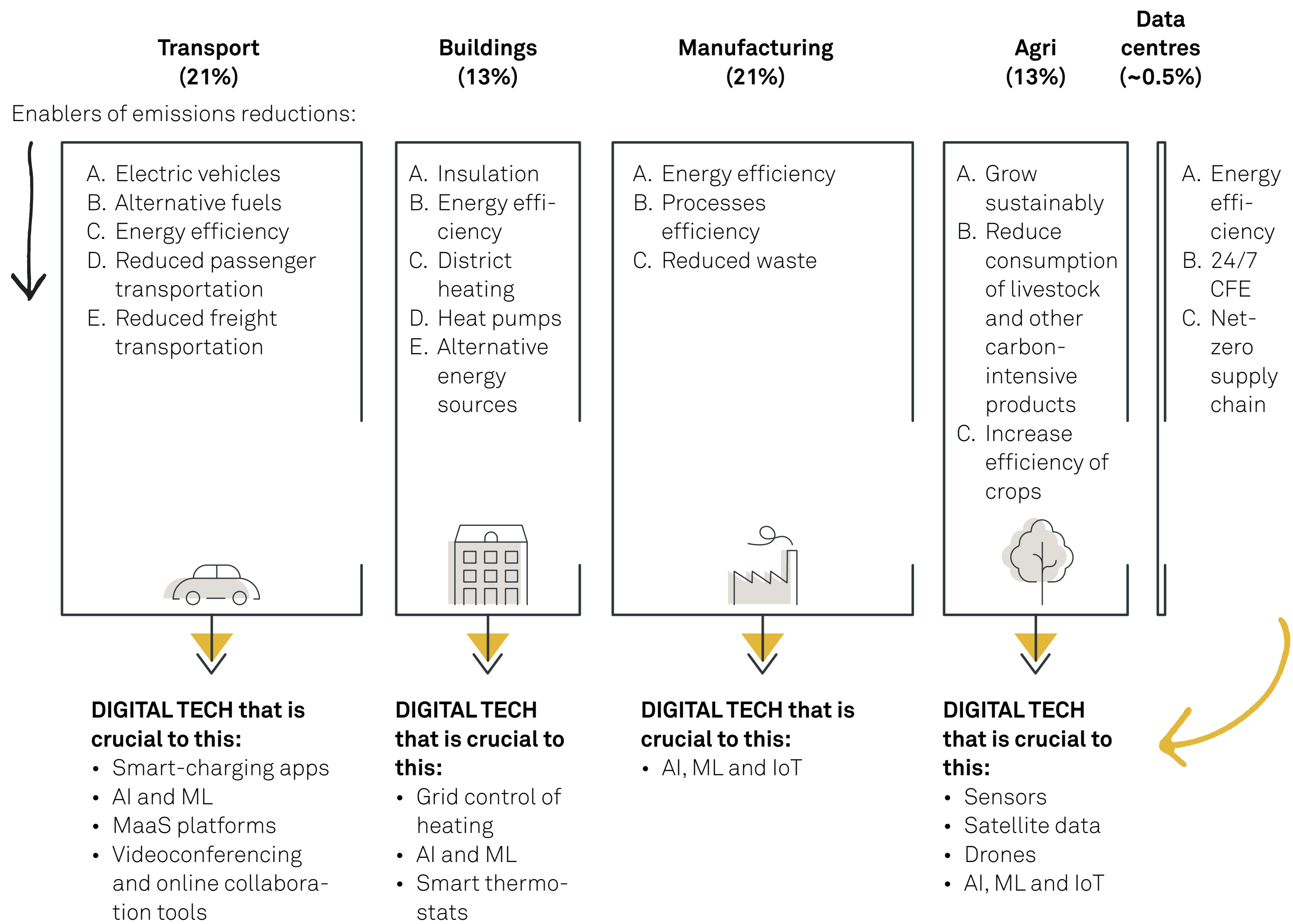
Note: GDP shown at constant prices and greenhouse gas emission based on absolute emissions. Level of digitalisation is determined by the DESI index measuring digital economy and society on a range of parameters such as skills, connectivity and uptake of digital technology. Implement analysis based on Eurostat data.

2.3. Digital decarbonisation happens across all major sectors

We explore the current and potential contribution of digital solutions and find that digital solutions are contributing to reductions across four major areas of our economy. These major areas, comprising of transport, buildings, manufacturing, and the agriculture sector, account for almost 70% of total EU emissions.

Figure 6.

Overview of climate mitigation initiatives across sectors and the role of digital solutions



Note: Implement illustration and analysis based on data from the EEA and the IEA.

2.4. Use cases show the potential of digital solutions

In sections 2.8–2.11 we summarise 18 use cases and the case collection at the end of the report provides more detail. The use cases identified are some of the more prominent ones and are primarily selected on three criteria:

1. They are already in use today.
2. There is an untapped potential between now and 2030.
3. There is knowledge and evidence about the effects of the applications in terms of its enabling contribution to climate mitigation.

This list of use cases is by no means exhaustive. It only shows the tip of the iceberg, where we have evidence of the effects and scale of the application.

Figure 7.

Overview of digital use cases for climate change mitigation

	Transport		Buildings	Manufacturing
Do differently	#1: Demand flexibility with smart charging of EVs		#12: Matching electricity supply and demand	
Digital technologies enable the transition to non-polluting alternatives	#2: Charging app for "on-the-road" charging			
	#3: Smart energy management systems for new logistics hubs			
Use less	#4: Eco-routing nudging drivers to drive lower-emission routes	#5: Flight comparison showing emission information	#13: Reducing energy use in large buildings with artificial intelligence	#17: Energy savings through process optimization
Digital technologies enable the reduction in resource use through human action or automation	#6: Dublin using Google's EIE and improving bike infrastructure	#7: MaaS nudging passengers towards greener transport	#14: Reducing energy use in individual homes with smart thermostats	#18: Waste reduction through improved demand forecasting
	#8: Ride sharing platforms optimising passenger load	#9: Digital technologies in freight transportation	#15: Reducing energy use in buildings with real-time data	
Stop using	#10: Digital solutions supporting increased work-from home		#16: Reduced demand for buildings through smarter use	
Digital technologies provide digital alternatives to previous usage	#11: Video-conferencing reducing business purpose air travel			

Note: Implement's own illustration.

2.5. Approach to assessing the enabling role of digital technologies

Digital innovation is seen as one of the driving forces behind the EU's shift to a zero-carbon economy. Digital technologies will play a role in decarbonising almost every corner of our society – hence, the grand idea of the twin green and digital transition.

To unlock their potential for climate change mitigation, one must first aim to understand the individual key components of this potential and identify the areas in which to act to accelerate impact. It is virtually impossible to identify all the ways in which digital technologies are or could be contributing to climate change mitigation. It is even harder to quantify the total potential of digital technologies' enabling role in climate change mitigation.

Digital technologies sometimes offer very direct emission reductions. An example of this is when an eco-routing app directly helps save fuel and reduce emissions per trip in urban areas. Most often, however, digital technologies enable green transformation together with other technologies. An example of this is when a smart charging app works together with smart and digitised electric vehicles, digitally enabled charging infrastructure, and real-time price data to enable an accelerated transition to electric cars. Attributing a portion of foregone emissions to the digital part of such a large-scale transformation is challenging and almost impossible.

The analytical approach taken in this report includes a review of the detailed subcomponents of the pathways to net-zero in the four main emitting sectors in the EU economy: transportation, buildings, manufacturing, and agriculture. The power sector is a major emitter and a sector with very large potential for applying digital technologies (see section 2.5), but to avoid the risk of double counting, we have assessed the potential from end-use sectors only.

For each of the four sectors, the pathways towards net-zero were divided into various subcomponents, which were then investigated in terms of their need for digital enablement. We then assessed the existing knowledge-base and existence of digital solutions in each of the subcomponents (see sections 2.8 to 2.11).

For example, in the transport sector, we find that a substantial number of digital solutions are needed in the transformation to electrical vehicles at the required scale and at socially acceptable costs. This does not mean that electrification could not happen without the enabling role of digital solutions, but it means that, according to our assessment, it would be unrealistic to expect this transformation to succeed at a reasonable cost without them. Therefore, we would see this potential as enabled by digital technologies (together with other technologies).

Conversely, another subcomponent of the pathway to a net-zero economy relates to improved insulation of our buildings and homes. While we cannot exclude the existence of digital solutions to aid this effort, we assess that digital solutions would not play an important role in this part of the transformation.

2.6. Overview of the results

All in all, the report finds that digital solutions play an important enabling role for at least 20–25% of the reductions required to achieve a net-zero economy in Europe – equivalent to the total emissions of France and Germany combined.[36]

The majority (more than half) of this potential relates to upcoming and large-scale electrification of our societies (see section 2.7). This comes from the electrification of cars, light trucks, and urban buses, as well as from replacing individual gas and oil boilers in buildings with carbon-free energy-powered heat pumps and from the electrification of lighter industrial processes. In all of these instances, digital technologies are critical enablers of the much-needed demand flexibility required to succeed with a net-zero electricity supply.[37]
The second largest part (around one third) of the identified potential relates to improved energy efficiency, enabled in part by digital solutions.[38] Finally, digital solutions are, to a minor extent (at approximately 1–5% of the potential), enabling demand reductions.[39] An example of this is the role of video conferencing and other digital tools in increasing the propensity to work from home, reducing the demand for commuting.

This approach finds that, from a sector perspective, the potential is largest within transportation, second largest in buildings, and finally in manufacturing and agriculture. However, this finding should be considered against the caveat that we cannot claim to have identified all potentials and enabling effects of digital solutions. We have identified and assessed use cases for which there are robust evidence around the effects and use cases which can be applied to large baseline emissions. This approach will likely overlook many enabling impacts of digital technologies.

Before diving into each of the four areas, we address the cross-cutting issue of increasing electrification, as this makes for a very significant part of the pathway to a net-zero economy across the four areas.

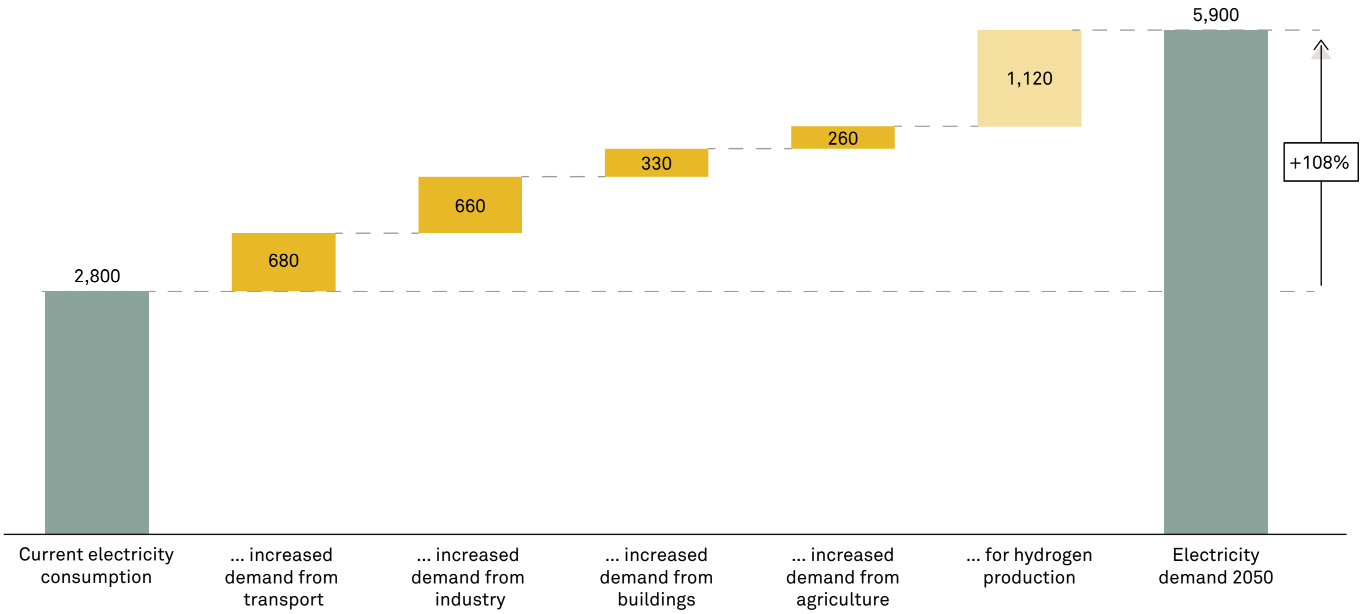
2.7. Electrification, renewables and demand flexibility

All key sectors will undergo significant electrification in order to cut emissions. Europe needs around 30 million electric vehicles by 2030.[40] Homes and buildings need around 10 million electric heat pumps for heating over the next five years, and many lighter industrial processes need to be electrified. The transformation also needs hydrogen and other green fuels from so-called power-to-x where electricity is a key input.

Projections suggest that electricity generation in the EU will need to double towards 2050 to power the green transition, which is an increase of 3,000 TWh.[41] This is equivalent to powering 280 million houses today.

Figure 8.

EU27 electricity demand
TWh



Note: Implement analysis based on "Net-Zero Europe – Decarbonization pathways and socioeconomic implications" report.

Along with building new carbon-free generation capacity, transmission and distribution grids will also need to be expanded and reinforced, and digital technologies will need to be built into the system to create a smart grid, including a digital twin of the electricity grid. The necessary investments have been estimated in the order of EUR 5 trillion over the next three decades and businesses will have to contribute to these costs in addition to the electricity bill and grid costs.[42]

Electricity generation from wind and solar is a cost-competitive but fluctuating energy source. The fluctuating power production requires that electricity demand must be more flexible in time. There will also be a need for more storage/battery solutions. Digital solutions are a key enabler of making demand more flexible as well as allowing us to better understand and simulate the grid systems.[43]

The role of demand flexibility and the increase in electrification will vary from grid area to grid area across Europe. Assessments performed in Denmark, where electricity use is expected to double, shows that the cost of electrification for an expanded grid and more renewable capacity will be reduced by 28% if demand can be shifted to periods of the day where electricity is more abundant, thereby shaving off peaks.[44]

Digitalisation is crucial for the demand flexibility of the future electricity system

Demand flexibility offers two important contributions:

- It maximises the use of renewable energy capacity by reducing the need for curtailments.
- It reduces the need for costly grid expansions by shaving the demand peaks that drive them.

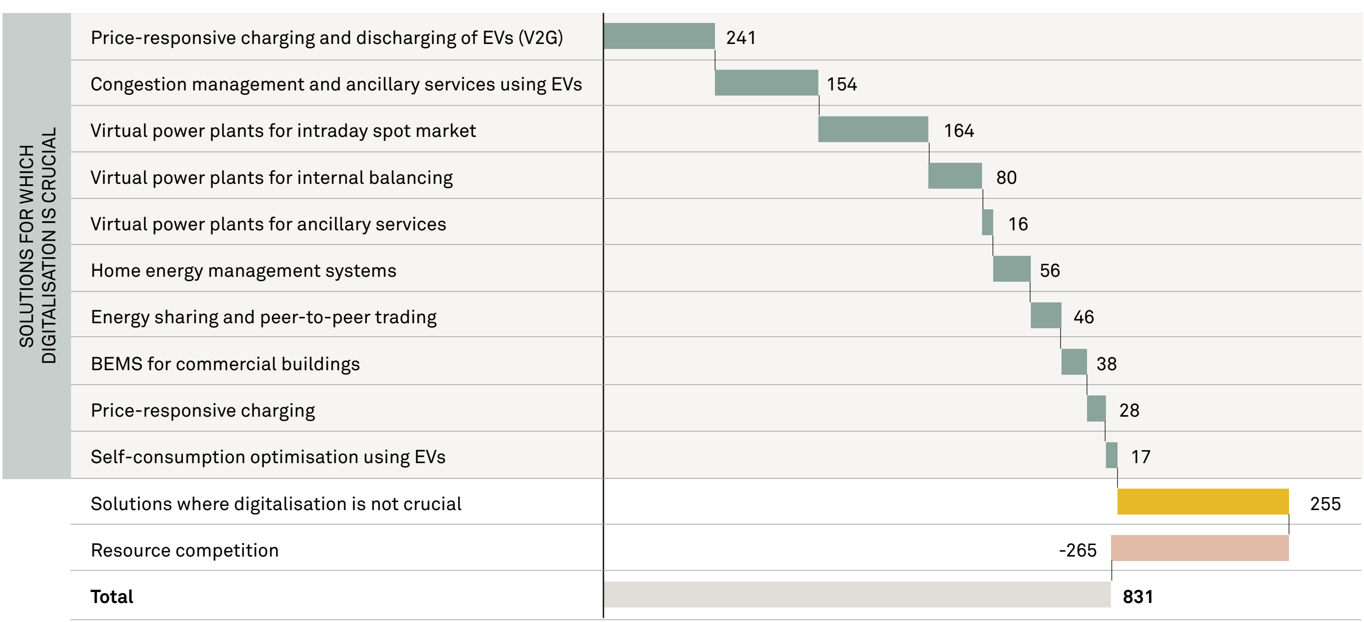
Digital technologies are key in enabling demand flexibility both by improving forecasts and automating real-time responses.

Digital technologies are estimated to contribute significantly to the flexibility solutions required as shown below. The most important digitally enabled applications towards this objective are:

- Price-responsive charging and discharging of EVs
- Congestion management of ancillary services using EVs
- Virtual power plants in various forms
- Home energy management systems
- Energy sharing and peer-to-peer trading

Figure 9.

Estimated flexibility potential up to 2050
GW



Note: Implement illustration adapted from EnTEC report.

2.8. Transport and digitally enabled climate mitigation

Digital technologies contribute to 60–70% of the needed emission reductions in the EU transport sector

- The EU domestic transport sector accounts for 721 $MtCO_2e$ emissions (in 2020), corresponding to 21% of total emissions in the EU. More than half of these come from cars.[45]

- The EC estimates that emissions from the domestic transport sector will need to decrease by 90% by 2050 for the EU to reach climate neutrality.[46]

- To achieve this goal, the EU has set out legislative changes under the "Fit for 55" package,[47] and a "Strategy for Sustainable and Smart Mobility",[48] whose objectives include increasing energy efficiency, increasing the uptake of zero-emission vehicles, ensuring a good infrastructure for alternative fuels, supporting digitalisation and automation, and improving connectivity and access.

- The EC recognises several green technology innovations in the transport sector that will be available on the market between today and 2050, such as EVs and Mobility-as-a-Service solutions, that can reduce the environmental burden of travelling.[49]

- The EC also recognises the importance of providing the right information to users to "improve the sustainability of their transport choices" in order to move towards a green and carbon-neutral economy.[50]

Digital technologies play a key role in enabling the transition to carbon-neutral transport.

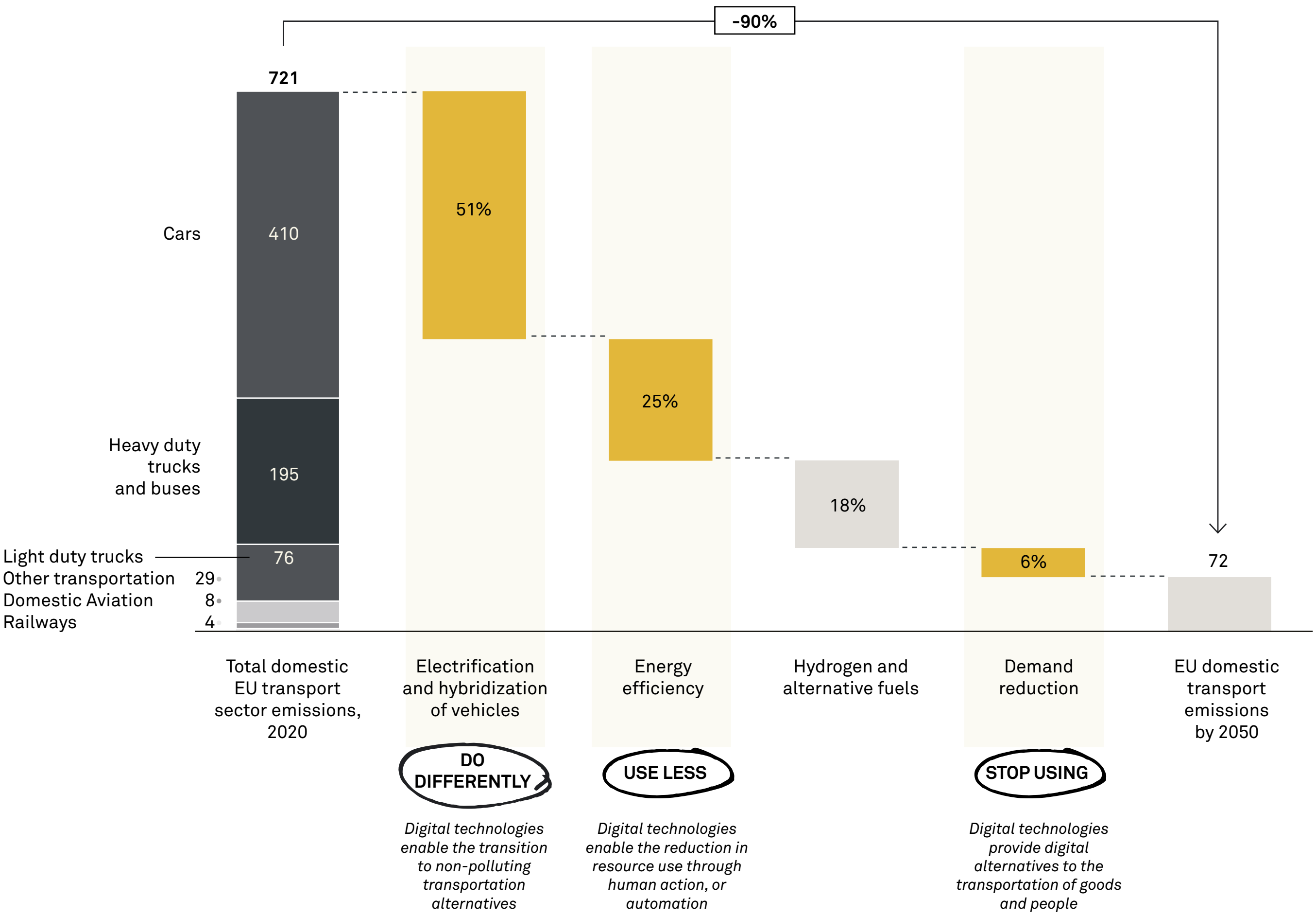
1) **DO DIFFERENTLY |** Half of the emission reductions in transport relates to the electrification of cars, light trucks and city buses. Digital technologies, and in particular smart charging technologies, are needed to enable the transition to electric vehicles and to ensure electrification at a socially acceptable cost (see use cases 1, 2 and 3).

2) **USE LESS |** Around 25% of the reduction comes from energy efficiency. Digital technologies also play a key enabling role in helping users improve the sustainability of their transport choices and thereby use fossil energy more efficiently and emit less CO_2 (see use cases 4, 5, 6, 7, 8 and 9).

3) **STOP USING |** Finally, demand for transport will need to be reduced, which is expected to account for around 6% of the total reduction. Digital technologies provide digital alternatives to transport of goods and people and thus reduced transport (see use cases 10 and 11).

Figure 10.

EU27 transport sector emissions, 2020 vs target reduction towards 2050
$MtCO_2e$



Note: Implement analysis based on data from the EEA and "Net-Zero Europe – Decarbonization pathways and socioeconomic implications" report.

Overview of digital use cases in transport

This section presents an overview of the use cases in the transport sector. The use cases in transport fall into three groups:

1. Supporting the electrification of transport.
2. Enabling energy efficiency and more sustainable transport choices.
3. Replacing travel by digital substitutes.

The use cases are described in more detail in the case collection at the end of the report.

Supporting the electrification of transport

Digital solutions are enabling the transition to electric vehicles in a number of ways.

- **Use case 1 and 2:** Smart charging apps for electric vehicles (such as Monta, EV Energy, and True energy) are crucial for ensuring user convenience and affordability and are key for demand flexibility. Furthermore, smart apps provide convenience for on-the-road charging and reduce "range anxiety" for EV users, thus supporting the transition to EV broadly speaking.

- **Use case 3:** Smart energy management systems are crucial for new logistics hubs such as the Amsterdam City Logistics Innovation Campus (CLIC) to electrify light trucks that can serve the city with supplies.

Impact: *The need for further electrification is significant. Analyses show that 40–50% of transport CO_2 emissions should be reduced through electrifying cars, light trucks and city buses which correspond to around 330 $MtCO_2e$ of 2020 emissions. Digital technology is an integrated part of the transformed and electrified transport system, along with other technologies (vehicles, charging infrastructure, grid).*

Enabling energy efficiency and more sustainable transport choices

Digital solutions are enabling higher energy efficiency and supporting more sustainable transport choices as shown by the following use cases:

- **Use case 4:** Eco-routing software for cars and trucks (such as the new eco-routing in Google Maps) can save fuel and reduce emissions per trip, for both passenger and freight transport.

- **Use case 5:** Flight comparison platforms providing emission information, as is now available in Google Flights and Skyscanner, can nudge travellers to choose more carbon efficient flight options, leading to emission reduction.

- **Use case 6:** Geo location and satellite data to improve green infrastructure in cities and achieve local green transport policies.

- **Use case 7:** MaaS platforms such as Google Maps, Donkey Republic, and Bolt facilitate a modal shift from private cars to public transport and non-polluting transport means (such as bikes and electric scooters), as well as making mobility more sustainable through the optimisation of processes.[51]

- **Use case 8:** Ride sharing platforms (both centralised such as Uber and Lyft and peer-to-peer such as BlaBlaCar and GoMore) contribute to lower emissions per passenger, by enabling higher utilisation of vehicles, reducing car ownership and in turn reducing the number of short journeys taken by car.

- **Use case 9:** Digital technologies optimising energy use in freight transport can alone save up to 20% in energy consumption.

Impact: *Improved energy efficiency is expected to drive 20–25% of the needed reduction in CO_2 emissions from transport towards 2050. This corresponds to 160 MtCO_2e of the 2020 level – equivalent to taking 35 million petrol cars off the road. Digital technology is a key enabler of more sustainable transport choices and thus contributing to energy efficiency in transport.*

Replacing travel with digital substitutes

Digital solutions can – to some degree – substitute the need for travel as shown by the below use cases:

- **Use case 10:** Cloud-based video conferencing and online tools such as Google Meet, Microsoft Teams, Miro boards and Slack enable working from home and thereby save emissions on commuting, albeit while increasing home emissions (until heat and electricity become carbon-free). Around one third of European employees can work from home. Recent data show that employees in this group work from home an average of 1.6 days more than before the pandemic.

Impact: *With consideration for increased home emissions, this digitally enabled change is creating a net saving corresponding to 2–3% of car emissions. This equals savings of 10–15 MtCO_2e per year in the EU compared to 2020 emissions.*

- **Use case 11:** Cloud-based video conferencing and online tools also reduce the need for business travel and thereby saves emissions on international flights. Around a quarter of all international air passengers used to travel for business purposes. Recent data and forecasts show that 20–25% of business passengers will not return after the pandemic.

Impact: *This digitally enabled change is saving between 4% and 6% of global emissions on commercial passenger flights, which corresponds to a reduction of international aviation emissions by 30–50 MtCO_2 globally on 2019 levels.*

2.9. Buildings and digitally enabled climate mitigation

Digital technologies contribute to 30–35% of the needed emission reductions in the EU buildings sector.

- Buildings in the EU emit 450 $MtCO_2e$ directly from gas boilers and other installations for heating and cooking. The direct emissions from buildings constituted 13% of total EU emissions in 2020.[52]

- In addition, our buildings emit 530 $MtCO_2e$ indirectly via the electricity and district heat consumed and with this, buildings account for 28% of total emissions.[53]

- Most energy in buildings is used for space and water heating (70%). The rest is consumed by appliances (15%), lighting (5%), cooking (5%), and space cooling and other (5%).

- The EU Climate Target Plan demands a 100% decrease in direct emissions from buildings by 2050.[54] A 60% reduction is needed by 2030 to meet the requirements of Fit for 55.[55]

- The phasing out of fossil fuels entails electrification, and thus decarbonisation hinges on the realisation of the target stated by the EC of 40% renewable energy sources in the EU's overall energy mix by 2030 and 100% in 2050.[56]

Digital technologies play a key role in enabling the transition to carbon-neutral buildings.

1) **DO DIFFERENTLY |** Digital technologies enable the transition to non-polluting energy alternatives, making renewable energy-based solutions, such as heat pumps powered by renewables, cost-efficient alternatives (see use case 12).

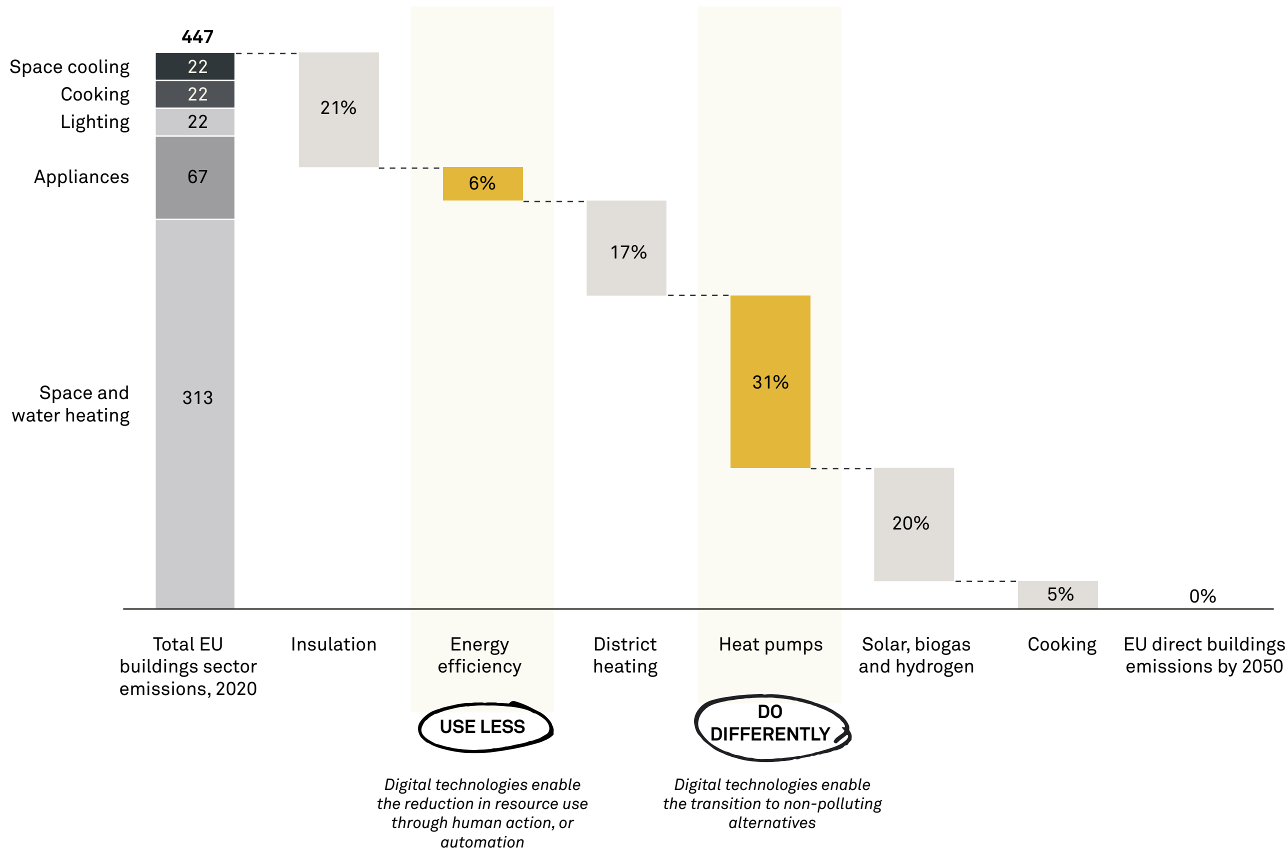
2) **USE LESS |** Digital technologies automatically reduce the use of resources, by optimising for perceived comfort (see use cases 13 and 14).

3) **USE LESS |** Digital technologies enable the reduction in use of resources through human action, by driving energy saving behaviour by gathering and presenting emissions data to consumers (see use case 15).

4) **STOP USING |** Digital technologies can reduce the demand for buildings by supplying platforms that enable smarter use of building space (see use case 16).

Figure 11.

EU27 residential and commercial buildings direct emissions, 2020 vs target reduction towards 2050
$MtCO_2e$



Note: Implement analysis based on data from the EEA and "Net-Zero Europe – Decarbonization pathways and socioeconomic implications" report.

Overview of digital use cases in buildings

This section presents an overview of the use cases in the building sector.

The use cases in buildings fall into four groups:

1. Supporting the electrification of heating in homes and buildings.
2. Increased energy efficiency with artificial intelligence.
3. Reduced energy use in buildings with real-time data.
4. Reduced demand for buildings through smarter use.

The use cases are described in more detail in the case collection at the end of the report.

Supporting the electrification of heating in homes and buildings

Electrification will also be part of the decarbonisation pathway for buildings and digital solutions will help to enable this via its contribution to demand flexibility:

- **Use case 12:** Advanced digital building control systems can exploit the temperature inertia in buildings and postpone/advance heating, ventilation, or air conditioning in response to the needs of the electricity supply. Such systems are already used in practice, for example by Avacon (DSO in Germany) and E.ON (DSO in Sweden).

Increased energy efficiency with artificial intelligence

Digital solutions are being used to improve the energy efficiency of both large buildings and individual homes.

- **Use case 13:** Advanced digital building control systems in large buildings use AI to reduce energy use. Research shows an average reduction of 20% to 40% depending on the type of approach, without reducing comfort levels. Examples already in use are found in office and residential buildings.[57] The uptake of such AI solutions is still in an early phase and only around 5%.

- **Use case 14:** Smart thermostats such as the Google Nest reduce emissions in individual homes by reducing the energy consumption for heating, ventilation, and air conditioning (HVAC) by between 10% and 12%.

Impact: *The combination of AI and smart thermostats in individual homes is already saving around 1% of direct emissions from buildings corresponding to 2–5 MtCO$_2$e of 2020 emissions. The potential for increased uptake is enormous. We estimate that AI and smart thermostats can save 5–6% of total direct CO$_2$ emissions from buildings towards 2050, corresponding to 25–30 MtCO$_2$e of 2020 emissions if deployed at scale.*

Reduced energy use in buildings with real-time data

Digital solutions help to collect, structure and display data in ways that enable behavioural change:

- **Use case 15:** Smart apps which collect, structure and display real-time energy consumption data can help users to reduce energy consumption. Studies show that if consumers are given access to real-time data on their own consumption, they reduce consumption by 1% to 15%. Examples include the DTE Smartphone Insight App, which motivates users to save energy by providing near-real-time feedback on home energy use, and weekly challenges for users.

Impact: *Initial studies estimate the savings at 1–3% for electricity and around 2% for gas after adjusting for savings by other utility programmes.*

Reduced demand for buildings through smarter use

Finally, digital solutions can enable a demand reduction via new business models and platforms:

- **Use case 16:** Digital sharing platforms and smart digital solutions contribute to reduced demand for buildings. Examples are higher utilisation of building space through workspace management systems, place and desk booking and sensor-based real-time understanding and forecasting of building use.[58]

Impact: *Not quantified*

2.10. Manufacturing and digitally enabled climate mitigation

Digital technologies also play an important role for enabling emission reductions in the EU manufacturing sector.

The EU manufacturing sector accounted for 21% of EU total emissions in 2020 (720 $MtCO_2e$). In the years before the pandemic, emissions from manufacturing accounted for around 30% of total carbon emissions.

Almost half of the total sector emissions come from the material processing industry (i.e., heavy industry such as steel, cement and glass), which requires extreme heat, which is very energy-intensive and hard to scale down.[59]

The EU manufacturing sector is covered by the EU emissions trading scheme (ETS) and the target is to reduce emissions by 43% compared to 2005 levels.[60]

Digital technologies can play an important role in reducing emissions in the manufacturing sector by helping to increase energy efficiency and reduce the use of resources.

- Electrification will be a solution for low and medium temperature heat generation by moving to heat pumps and electric boilers. Electrification of boilers and furnaces that currently use fossil fuels would reduce industry emissions by 13%.[61]

- Overall data collection enhances companies' ability to track scope 3 emission and ESG impacts from suppliers (e.g. Unilever using digital tech to monitor and disclose progress in its goal of a deforestation-free supply chain by 2023).[62]

- AI-enhanced supply chain efficiency (e.g., transporting more goods fewer kilometres by enhancing packaging and planning). Robotics used in waste sorting enabling the transition to a circular economy.[63]

Estimating the share of reductions that are enabled by digital solutions is very difficult in manufacturing. Based on the available evidence and use cases, this report estimates conservatively that around 10–15% of the needed reductions in manufacturing will rely on different kinds of digital enablement.

Overview of digital use cases in manufacturing

This section presents an overview of the use cases in the manufacturing sector, which fall into two groups:

1. Energy efficiencies with digitally enabled process optimisation.
2. Reducing overproduction with digitally enabled demand forecasting.

The use cases are described in more detail in the case collection at the end.

Energy efficiencies with digitally enabled process optimisation

Digital solutions are used to optimise production processes at the factory floor and in the supply chain and is increasingly used for energy efficiency purposes as demonstrated below:

- **Use case 17:** AI and IoT are used to monitor, predict, and suggest energy savings (and cost savings) without compromising production.

Examples of applications

- **Henkel**, a German multinational chemical and consumer goods company, achieved a 10% reduction in CO_2 emissions using sensors across production sites to provide feedback and real-time data for benchmarking (and 25% overall reduction in energy consumption).

- **Ericsson**, the Swedish telecom manufacturer, uses advanced IoT sensors to monitor and reduce energy and water usage. The efficient design of the factory combined with the use of these technologies has resulted in a 97% reduction in carbon emissions, as well as reductions of 14% in water consumption and 24% in electricity use relative to comparable factories.[64]

- **Schneider Electric,** a German electronics producer, uses IoT with predictive analytics to reduce its energy use by 26%, water usage by 20% and carbon emissions by 30%.[65]

- **Renault,** the French car manufacturer, uses a Google Cloud-based energy consumption dashboard, which monitors energy use and suggests actions to reduce it. This has resulted in a 10–20% reduction in overall energy use.[66]

Impact: *Estimates of the CO_2 reduction potential from using AI to optimise the manufacturing process ranges between 5–10% which amounts to a reduction potential of 36 $MtCO_2e$ if applied at a European scale.*

Waste reduction through improved demand forecasting

Overproduction is a sizeable issue in the fashion industry and in the food industry and digital solutions are helping to reduce this as shown by the following cases:

- **Use case 18:** Machine learning is used for better demand forecasting. Better demand forecasts mean production can better match demand, thus reducing waste (overproduction). Less production means less energy use and hence fewer emissions. The potential is especially large in the fashion industry (20% of clothes produced are never sold) and in the food industry (33% is never sold). A study of the global fashion industry has estimated a potential for reducing CO_2 emissions by 3–6% by using demand forecasting technology to reduce overproduction by 2030.[67] This estimate shows the potential in the fashion industry and cannot be extrapolated to other industries.

Examples of applications

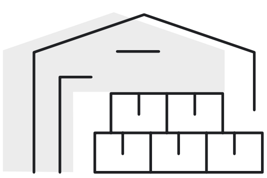
- **Nestlé,** the global food producer, uses machine learning to predict demand and this has cut 14–20% of inventory safety stock.

2.11. Agriculture and digitally enabled climate mitigation

The agriculture sector is one of the largest emitters. The EU agriculture sector accounts for around 460 $MtCO_2e$ emissions (in 2020), corresponding to 13% of total emissions in the EU.[68] On top of this, it is also one of the major users of water,[69] and damages terrain and water flows.

The EU's goals for agriculture, under the European Green Deal, propose to "reduce the environmental and climate footprint of the EU food system" and to "strengthen the EU food system's resilience".[70]

The agriculture sector is already running at maximum capacity, but it will need to produce 30–50% more output to keep up with a growing population.[71] At the same time, the sector is one of the least innovative and digitalised.[72] Finally, changing climate conditions will make it even harder to produce the necessary food supply for the global population.[73]



Digital technologies play a key role in ensuring that we will be able to feed the planet sustainably in the future – by doing differently and using less.

- Digital technologies can collect relevant data on fields and crops, such as field boundaries, land use, farmers' practices, number of grains on a wheat head, and digitalise the data to provide new insights. Examples of such technologies are satellite data, in-situ sensors, drones, and crop water stress monitoring and control systems. Mineral (Google's moonshot factory X) is developing technologies that collect data across the world and feed it into an AI model.[74] Accurate, updated, and actionable information can inform policymakers, support them in their decisions and track the impact.

- Digital technologies can increase the efficiency of crops. Digital technologies can increase efficiency and total output while using limited resources through a more targeted application of feed, water, energy, fertilisers, and pesticides. Examples of digital technologies in this space are smart farming, in-situ sensors, digital twins, AI-based plant disease recognition tools, and Breeding by Design.[75] Mineral's gene-bank project in Colombia is an example of such use of digital technologies.[76] Microsoft's project in Spain, based on IoT, data analytics, and AI, helps achieve greater efficiency in agriculture.[77] IoT applications used in irrigation can supply the required water directly to the roots of the crop, increasing efficiency and reducing water consumption.

- Digital technologies can inform farmers on how to grow sustainably and to improve productivity. Currently, farming is a primarily analogue occupation. Providing farmers with digital tools to both collect data and receive relevant information can help increase productivity while producing sustainably. Mineral is developing new technologies in this space to support farmers.[78] Moreover, blockchain technology can provide transparent and trusted information across the agriculture value chain on ethical practices and carbon emissions.

Previous estimates suggest that digital solutions have the potential to reduce the greenhouse gas emissions from agriculture by 20–25%.[79]

2.12. Trade and digitally enabled climate mitigation

This section looks into the cross-cutting topic of international trade in relation to the international trade in digital services enabling climate mitigation.

International trade is important to ensure that the most efficient digital solutions can spread globally

International trade can support climate mitigation by increasing the availability of digital solutions and services enabling climate change mitigation. Reducing trade barriers on such digital solutions will accelerate the spreading of the most efficient solutions. For example, eliminating tariffs and non-tariff barriers on certain clean energy technologies and energy efficiency products could increase their trade volume by 14% and 60%, respectively.[80]

As shown in previous sections, digital technologies play an important enabling role in climate mitigation, and high standards in digital trade can make best-in-class technologies available across borders. In addition, digital solutions can also decarbonise the trade activity in itself through digital solutions that help steering ships along the most climate efficient routes, or AI applications helping to avoid empty transport of containers.

A global regulatory framework for trade in digital services is important

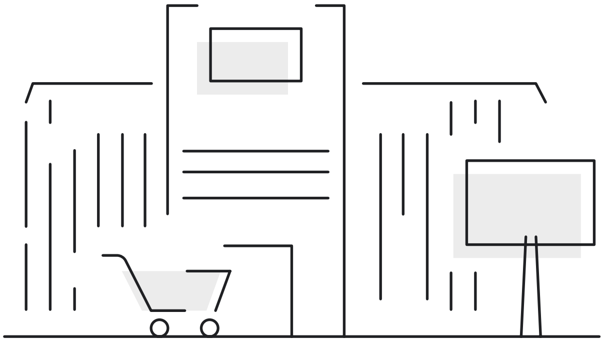
It is essential for global decarbonisation that digital technology can be freely traded under transparent regulatory conditions and high global standards. Access to global markets gives firms the opportunity to scale up innovative technologies and the incentive to invest in R&D activities.

Trade barriers (tariffs, costly regulatory barriers, or discrimination against foreign suppliers) can also have broader adverse environmental impacts which risk slowing down or even hindering the uptake of the technologies necessary to enhance biodiversity, reduce deforestation, improve water management, etc. The necessary technologies are being developed at a high pace, and the first movers have the opportunity to set global standards.

The Environmental Goods Agreement (EGA) is an attempt by some World Trade Organisation (WTO) Members to reduce tariffs on goods that can help achieve environmental and climate protection goals, such as generating clean and carbon-free energy, improving energy and resource efficiency, controlling air pollution, managing waste, treating wastewater, monitoring the quality of the environment, and combating noise pollution. Negotiations over the EGA have been stalled (the 18th round of EGA negotiations took place in 2016), and trade barriers to environmental goods continue to compromise the achievement of global climate targets.

According to the World Economic Forum, the deployment of technologies for decarbonisation depends on a wide range of supporting climate-related services, such as installation, technical testing and analysis, education, advice, consultation, management, repairs, computers and research and development. Digital services (defined as telecommunication, broadcasting, and information supply services) form one of three priority areas of indispensable climate-related services.[81] The other two priority areas are Professional, Technical, and Business Services and Construction and Infrastructure Services.

As digital technologies contribute substantially and positively to many environmental objectives, trade policy can help ensure that firms and consumers have access to the most effective digital technologies at the lowest costs possible). Enabling European exports of environmental services and securing access to the most efficient technologies require high standards and commitments to digital trade. However, even the establishment of a truly Single Market in (environmental) services is lagging behind the dismantling of barriers to the free flow of goods, capital, and people.[82] In addition, the pace of new EU trade deals has slowed down.



The EU's external trade policy is reflecting the importance of trade in digital services

The growing importance of digital trade is reflected in the EU's trade policy communication, An Open, Sustainable and Assertive Trade Policy, from 2021.[83] The communication emphasises that "trade policy will play a vital role in attaining the EU's objectives linked to the digital transition. European businesses rely on digital services, and this will only increase".

The increasing strategic priority of the EU to ensure digital trade is also reflected in the self-standing chapter on digital trade in modern bilateral trade agreements.[84]

The overarching goals of digital trade chapter in the EU's trade agreements are:

1. To ensure predictability and legal certainty for businesses.
2. To ensure a secure online environment for consumers.
3. To remove unjustified barriers.

The digital trade chapter contains almost 20 binding provisions on a wide range of issues, including the following:

- Banning customs duties on electronic transmissions.
- Promoting electronic contracts, electronic authentication methods and electronic trust services (such as e-signatures, e-seals and time stamps), which are necessary for the validation of online transactions and thus constitute a key enabler of digital trade.
- Ensuring online consumer protection, including spam.
- Prohibiting unjustified government access to software source code.
- Prohibiting unjustified barriers to data flows, including data localisation requirements, and protecting privacy.
- Facilitating regulatory cooperation.

Initiatives to reduce barriers to trade in digital services not only have important sustainability implications by enabling trade in climate-related services (and thereby indirectly in environmental goods). These initiatives also facilitate the substitution of traditional carbon-intensive goods with carbon-neutral alternatives (video calls, streaming, etc.), and make international trade more sustainable (by decarbonising transport, logistics and storage).

Such initiatives could include removing data localisation barriers, such as unnecessary requirements to store data in a particular jurisdiction or locate computing facilities locally, as well as outright bans on cross-border data flows. Other initiatives could target technology barriers related, for example, to security standards and requirements to disclose encryption algorithms or other proprietary source code. Finally, removing barriers to Internet services in existing regulatory regimes could pave the way for new business models and reduce the costs of using Internet platforms.[85]

Digital solutions will help accelerate independence from Russian gas

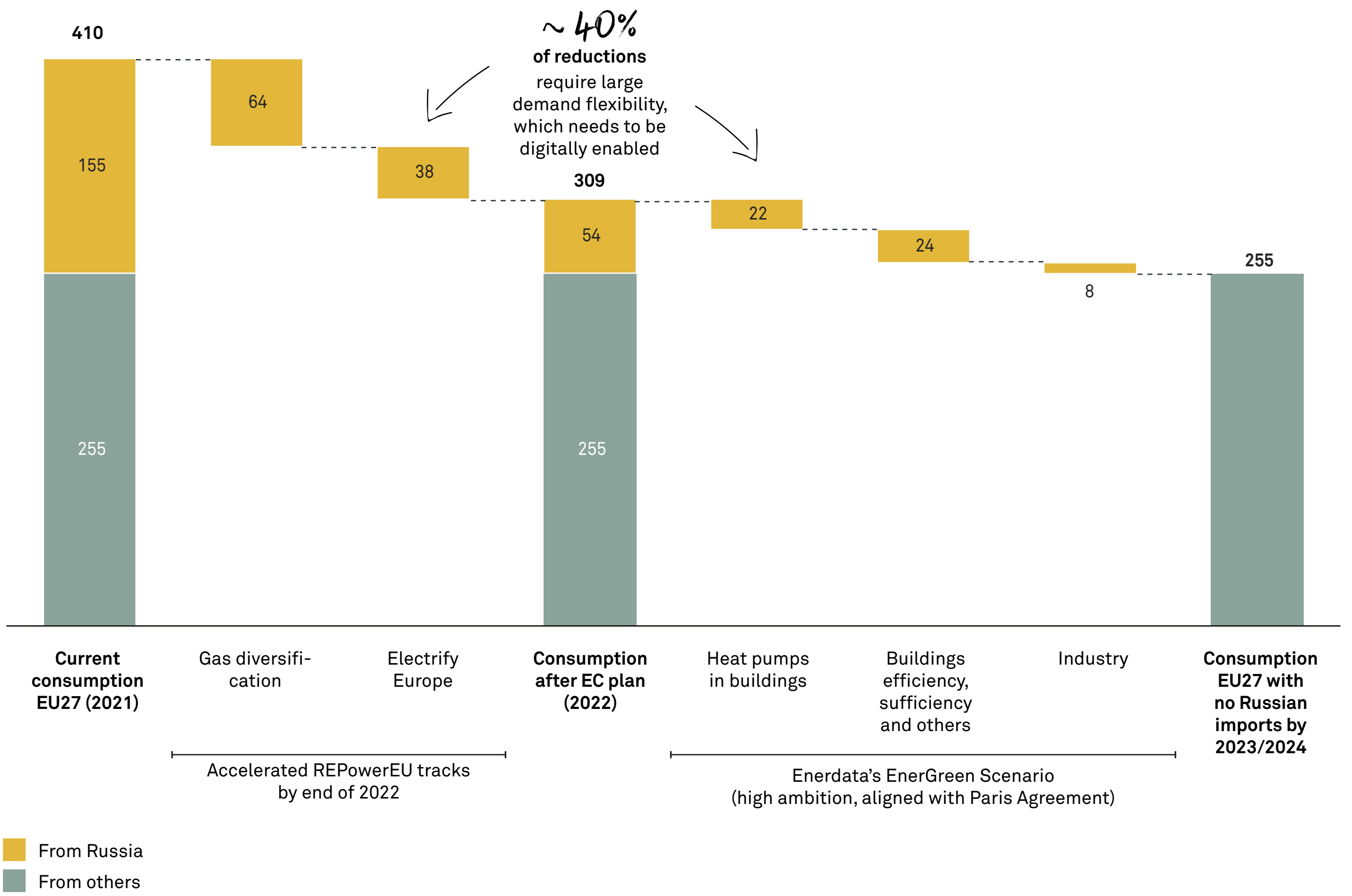
- In the short term, digital solutions play a vital role in Europe's response to the ongoing energy crisis. The current initiatives to accelerate the REPowerEU plan are expected to reduce dependence on Russian gas by two-thirds, reducing the Russian import need from around the current 150 billion cubic metres to a new level of around 50–60 billion cubic metres by the end of 2022. Even with this tremendous effort, there would still be around 50 billion cubic metres of Russian imports needed.

- With reduction of the remaining import need in mind, we have assessed the long-term scenarios for taking gas out of the European energy supply which would in any event be needed to achieve the 2030 target of a net 55% reduction from 1990 levels in domestic greenhouse gas emissions.

- Under the ambitious ENERDATA scenario, the EU can achieve independence from Russian gas by 2024 if the proposed measures in the scenario are applied.[86] Looking more closely at that transition, we find that a substantial part (~40%) of the pathway to diversify away from gas will require accelerating digitalisation of the energy system.

Figure 12.

Natural gas consumption in the EU27
Billion cubic meters



Note: Implement analysis based on data from the European Commission and Enerdata.

CHAPTER 3: Decarbonising digital

Mitigating the impact of technology on climate change

This part of the report discusses how to minimise the negative environmental impact of the digital sector and facilitate the progress towards a fully carbon-free digital sector.

Here, we focus our attention on the energy use and carbon emissions related to the operation of data centres. Although they are only responsible for part of the total footprint of the digital sector (see section 1.7), data centres are a segment of the digital sector that are under the direct control of tech companies, and where tech companies can act – and have acted – to minimise their environmental impact.

3.1. The tech sector is driving the transition towards zero carbon

The demand for digital services has grown exponentially in the past and is seen by many as a key building block for the society of the future, including as a key lever to achieve a net-zero carbon economy (as described in Chapter 2).[87]

Digitalisation is being driven by the proliferation of a number of consumer services, such as video conferencing and social networking. Technologies like machine learning, blockchain and edge computing are expected to further fuel the growth of digitalisation. Crypto mining is not included in our definition of digitalisation of the tech sector.

The tech sector has been at the forefront of corporate efforts to reduce the climate impact of their activities, making use of the best available instruments and continuously redefining corporate climate and clean energy ambition.

For example, the tech sector was among the first to move from carbon-free energy credits to acquiring additional carbon-free energy through power purchase agreements (PPAs) and has been responsible for 45% of new carbon-free energy deployed through PPAs between 2010–2020[88].

Many are going even further. After meeting its goal to match 100% of its electricity consumption with carbon-free energy on an annual basis, Google became the first major company to commit to operating on 24/7 carbon-free energy (CFE), which it aims to do at all of its data centres and office campuses across the world by 2030.[89] Other companies such as Microsoft and Iron Mountain are also on this journey. A new global effort has been created under Sustainable Energy for All and UN-Energy to coordinate among companies, governments, and non-governmental organisations to develop new solutions to this challenge.[90]

A Princeton University study has shown that 24/7 carbon-free electricity (CFE) procurement can drive much deeper reductions in carbon emissions from electricity consumption than the traditional approach of annual volumetric matching of demand with carbon-free energy purchases. Based on advanced simulations of the electricity system in the US, the study finds that 100% annual volumetric matching would only correspond to an hourly CFE match of 62% to 75% for the key Eastern electricity market (PJM interconnection) and California, respectively.[91]

The next step is to also achieve net-zero emissions across its entire value chain, which Google, Microsoft, and Meta have committed to by 2030.

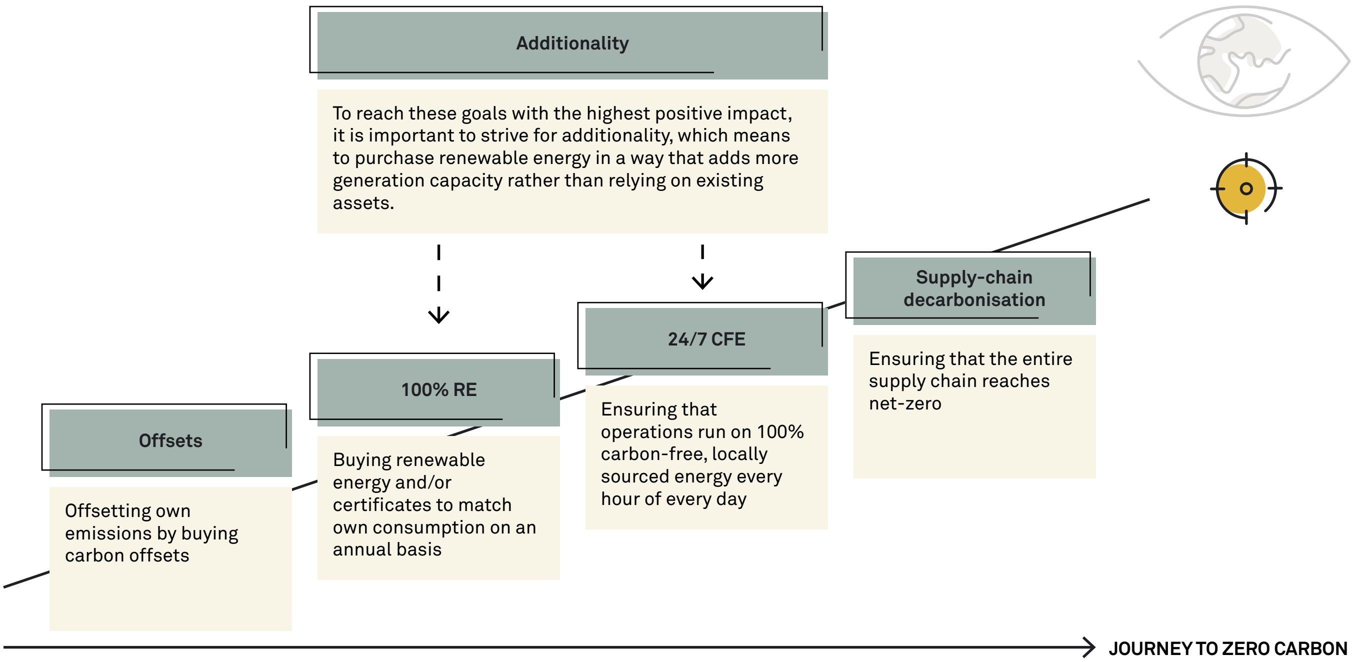
24/7 Carbon-free Energy

24/7 Carbon-free Energy (CFE) means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources, every hour of every day, everywhere.

Source: **UN 24/7 Carbon-free Energy Compact**

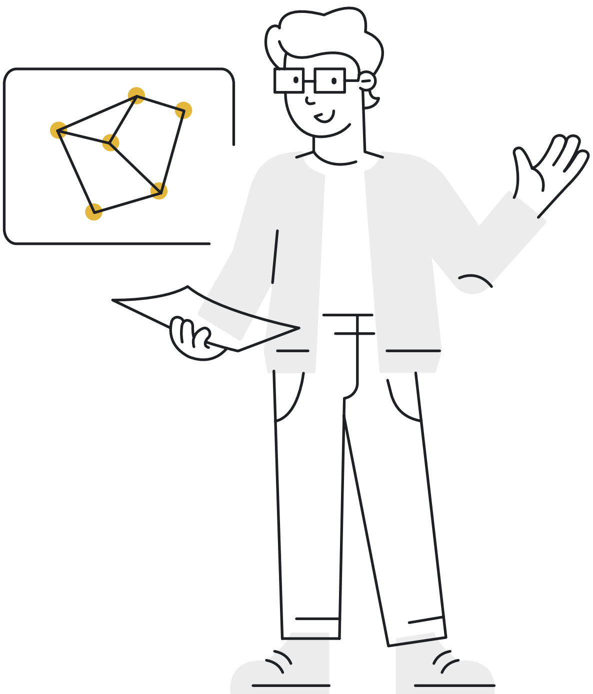
Figure 13.

Steps in the tech industry's decarbonisation journey



Note: Implement illustration.

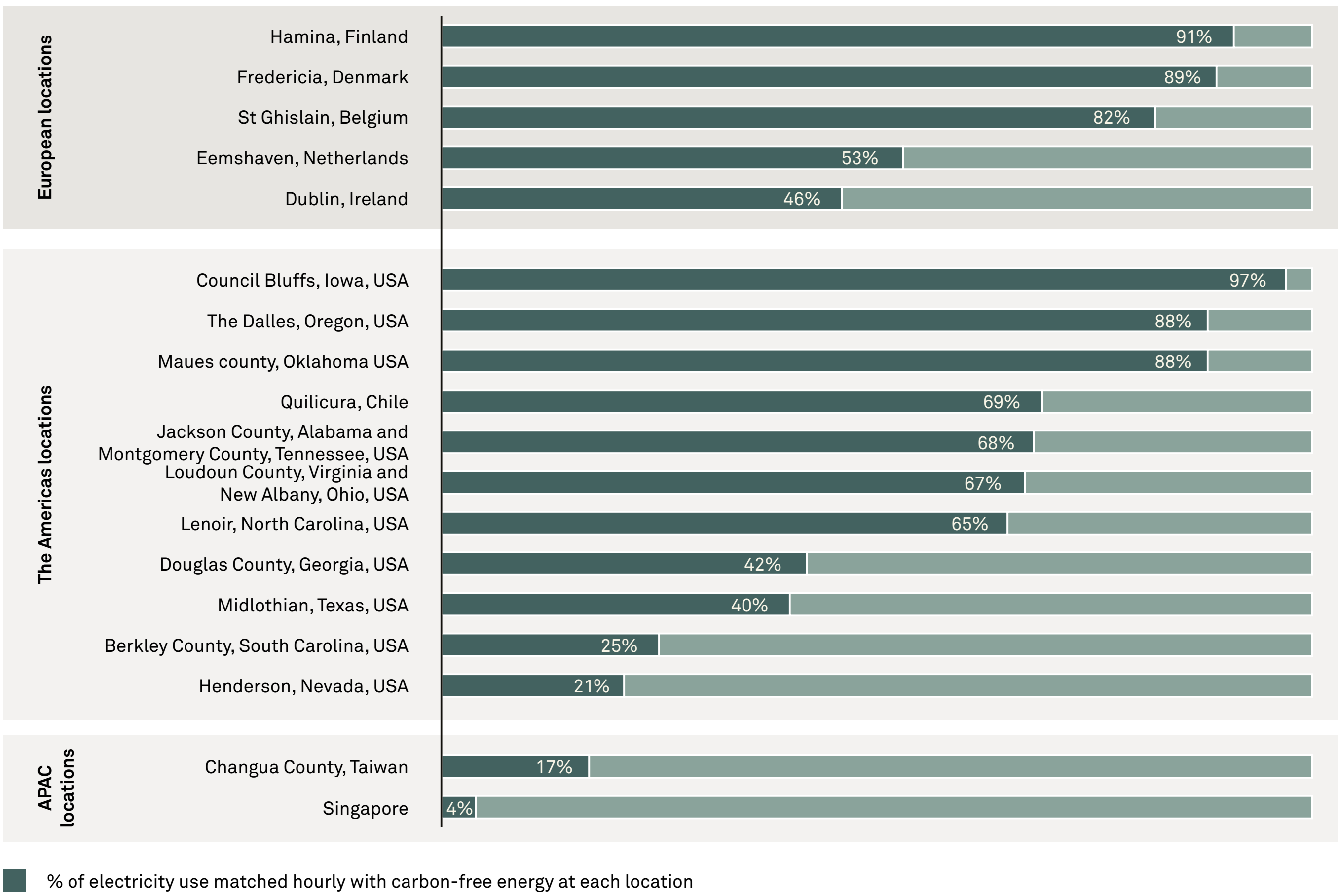
24/7 CFE represents a radical shift in the way tech companies pursue sustainability. It recognises the complexities of the energy system and acknowledges that adding more carbon-free energy alone will not lead to a carbon-free future if fossil fuels are still used when the wind is not blowing or the sun is not shining. Enabling 24/7 carbon-free energy will require innovations in technology and markets.



Based on 2021 data, three of Google's five European data centres operate at more than 80% carbon-free electricity (namely, in Finland, Denmark and Belgium) and two (Finland and Denmark) operate at around 90% carbon-free electricity on an hourly basis. This means that these locations are well-advanced towards 100% carbon-free energy. It is also clear that the last 10–20% of decarbonisation is the hardest to achieve, and a lot of effort is still needed to achieve 100% carbon-free energy even at the best performing locations. Modelling from TU Berlin shows that the step from 80% to 100% carbon-free electricity is just as expensive as the step from 0 to 80%.[92]

Figure 14.

Carbon-free electricity at Google data centres 2021
Percent of total electricity use at each location



Note: Google CFE% is the average percentage of carbon free energy consumed in a particular location on an hourly basis, while taking into account the investments made in carbon-free energy in that location. This means that in addition to the carbon-free energy that is already supplied by the grid, Google has added carbon-free energy generation in that location. Implement analysis based on public data from Google.

Delivering on the ambitious target of 24/7 carbon-free electricity at all data centres by 2030 – which is unique to the tech industry – can only be achieved by combining many different levers and building on years of experience and expertise.

As with PPAs and additionality, the tech industry is pushing the CFE agenda for others to follow by making concrete steps.

There are three overall drivers to making the 24/7 carbon-free target possible:

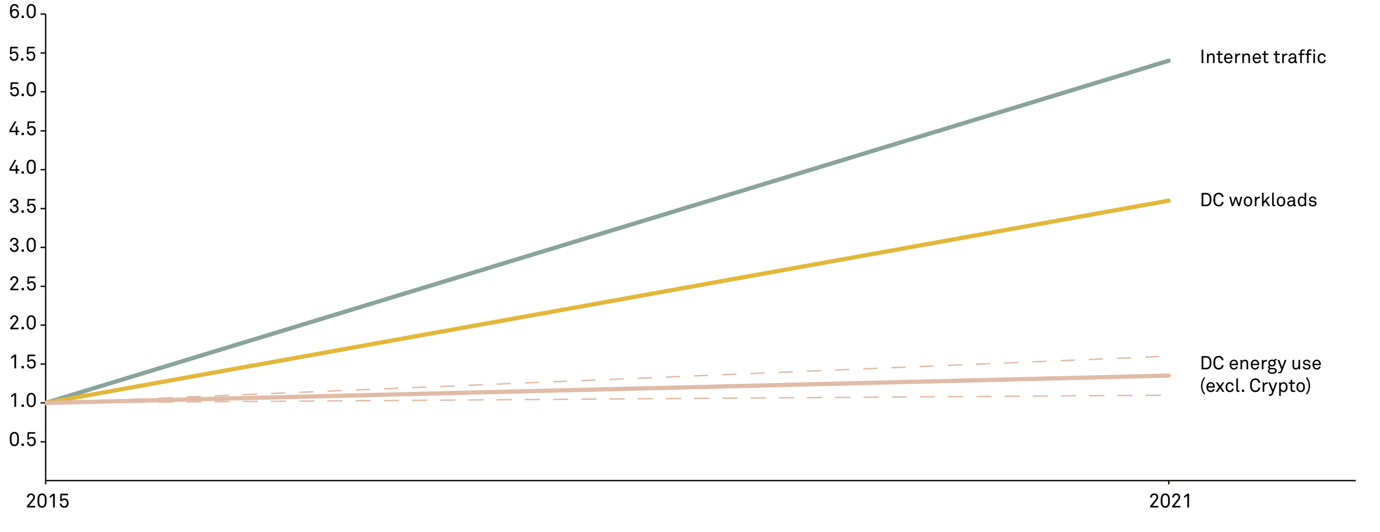
1. Continued energy efficiency improvements.
2. New carbon-free generation technology.
3. Load shifting and electricity storage.

3.2. Energy efficiency boost from shifts to cloud and hyper scale

The exponential growth in digitalisation has been met with surprisingly limited increases in electricity use. Despite a very significant, over fourfold increase in internet traffic between 2015 and 2021, and the doubling of data centre workloads, data centre energy use has only grown by 10–60% in the same period.[93] Estimates suggest the data centre industry consumes around 1–1.5% of global electricity,[94] although this number is associated with much uncertainty.

Figure 15.

Internet traffic, datacentre workloads and energy use
Index (2015 = 1)



Note: Figure reproduced from the IEA.

This tremendous increase in energy efficiency in data centres can be explained by the shift from local to cloud-based servers, and the shift to efficient so-called hyperscale data centres.

The achievements are a combination of efficiency gains in three domains: servers, storage and infrastructure; resulting in overall energy efficiency improvements of 20–25% per year.[95]

- For server computing, greater server virtualisation has enabled a six-fold increase in compute instances with only a 24% increase in global server energy use.[96]
- For storage, the combination of increased storage-drive efficiencies and densities has enabled a 26-fold increase in storage capacity with only a fourfold increase in global storage energy use.
- For infrastructure such as cooling and other non-compute energy, the energy usage is actually 20% lower globally in 2018 than in 2010. This is explained by ongoing shifts in servers away from smaller traditional data centres (79% of compute instances in 2010) and toward larger and more energy efficient cloud (including hyperscale) data centres (89% of compute instances in 2018), which have much lower reported PUE values owing to cutting-edge cooling and power-supply systems.

Figure 16.

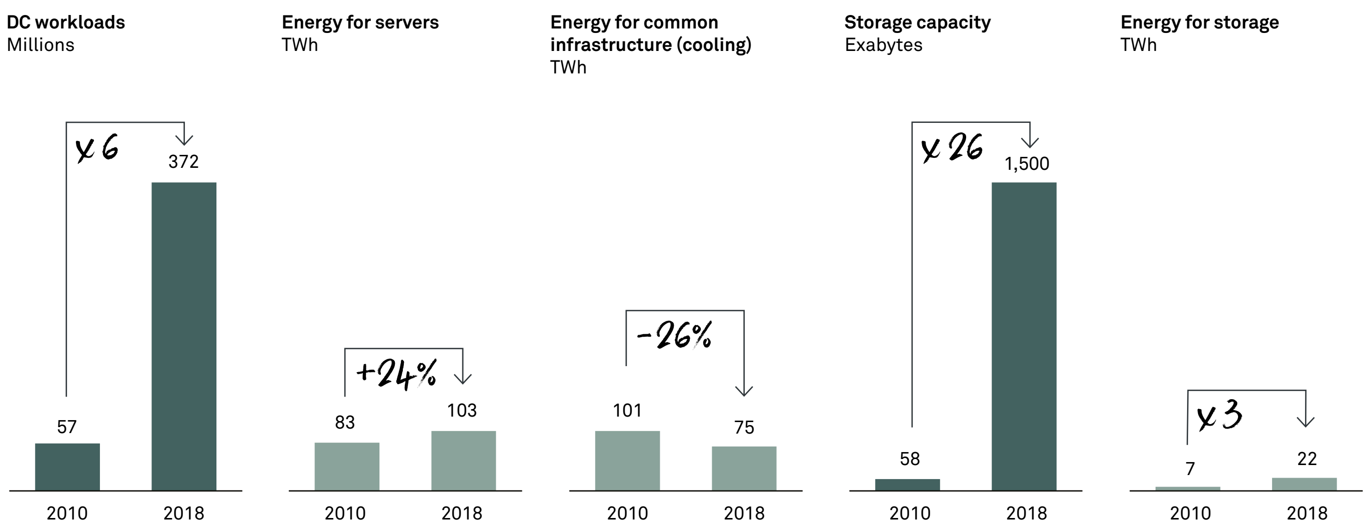
Data processing at data centres globally

Six times more with only 24% more electricity use...

...and 26% less energy for cooling and other infrastructure thanks to shift to hyperscale data centres.

Data storage at data centres globally

26-fold increase with only three times more electricity use.



Note: Implement analysis based on IEA analysis and data from Masanet et al. (2020).

Technical efficiencies for servers and storage are contributing to overall efficiency gains

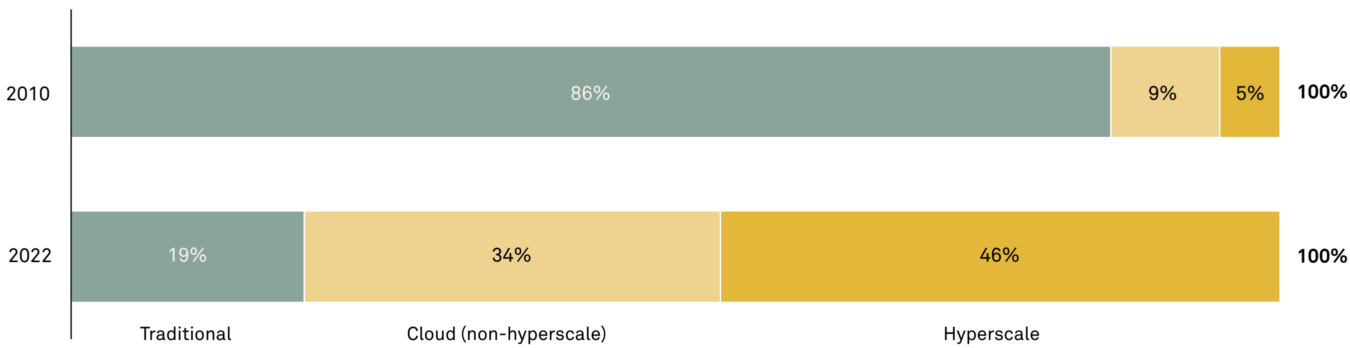
x 4 Since 2010, electricity use per computation of a typical volume server has dropped by a factor of four, largely owing to processor-efficiency improvements and reductions in idle power.[97]

x 9 Watts per terabyte of installed storage has dropped by an estimated factor of nine owing to storage-drive density and efficiency gains.[98]

Efficiency improvements will continue, but their pace is uncertain. The hyperscale transition has been a major efficiency driver, and hyperscale still only accounts for 46% of total data centre energy use.

Figure 17.

Data centre energy use globally by data centre type
Percentage distribution



Note: Implement analysis based on data from the IEA.

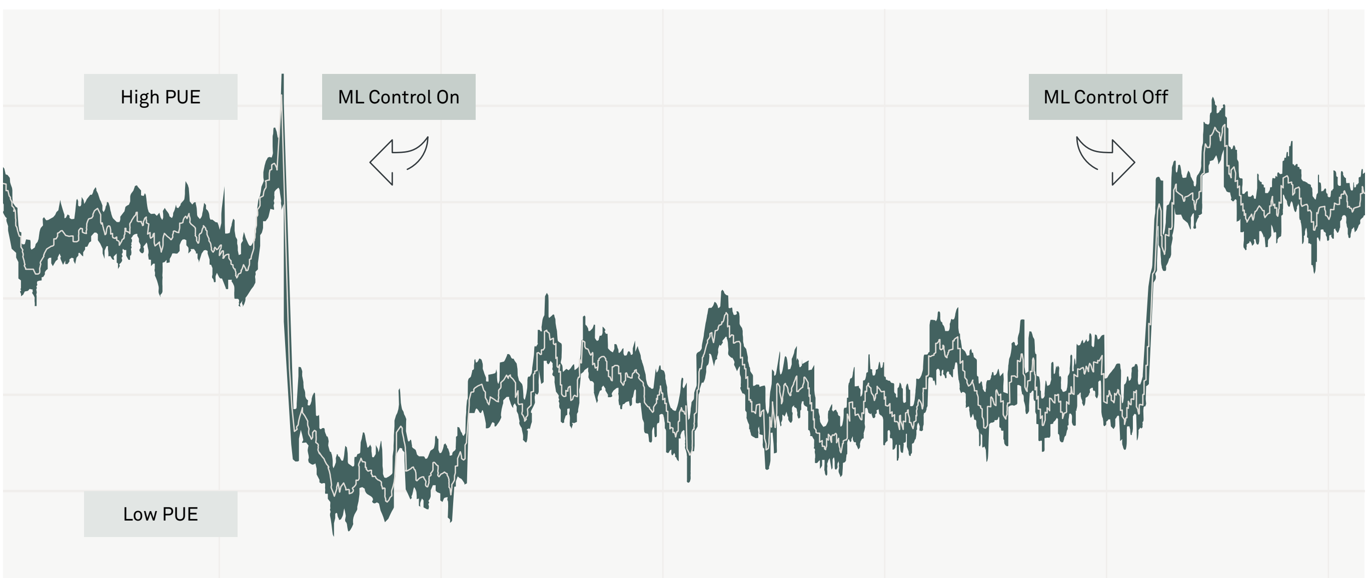
The tech industry is focusing significant attention on other drivers of future energy efficiency gains such as:

- The increased use of server virtualisation and the automation of cooling system control through applications such as machine learning and AI.
- The use of waste heat from hyperscale DCs in local district heating systems.
- The push to increase server energy efficiency, supported by the development of updated metrics that go beyond PUE, spearheaded by the industry association The Green Grid.

It is also worth mentioning that quantum computing could be a game-changer in the energy efficiency of data centres. It is still unclear, however, to which extent the increased cooling needs for operation close to absolute zero temperatures will offset the exponential increase in computing efficiency when the technology is used at scale.

Figure 18.

Power usage effectiveness at a data centre with and without machine learning control
PUE index



Note: Figure reproduced from DeepMind.

Predicting future electricity consumption by the data centre industry is notoriously difficult. It depends on the balance between increasing demand for services and continued gains in energy efficiency. The possible increase in data centre electricity consumption will be part of the existing electrification journey that all leading economies will go through in the coming decade (see section 2.1).

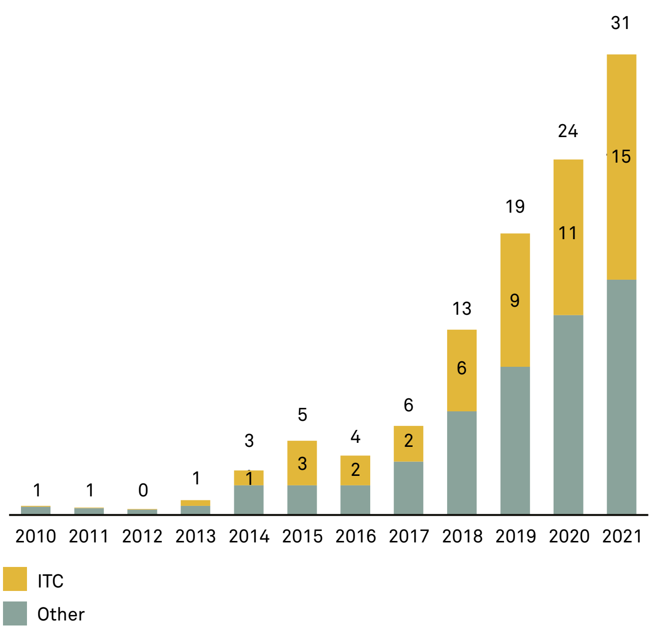
3.3. Carbon-free electricity building on long experience

Purchases of carbon-free energy have been a priority for many tech companies for decades. In 2010, Google started directly purchasing carbon-free electricity through PPAs, and in 2017 became the first major company to match 100% of its annual electricity use with carbon-free energy. This has been achieved largely through wind and solar technologies.

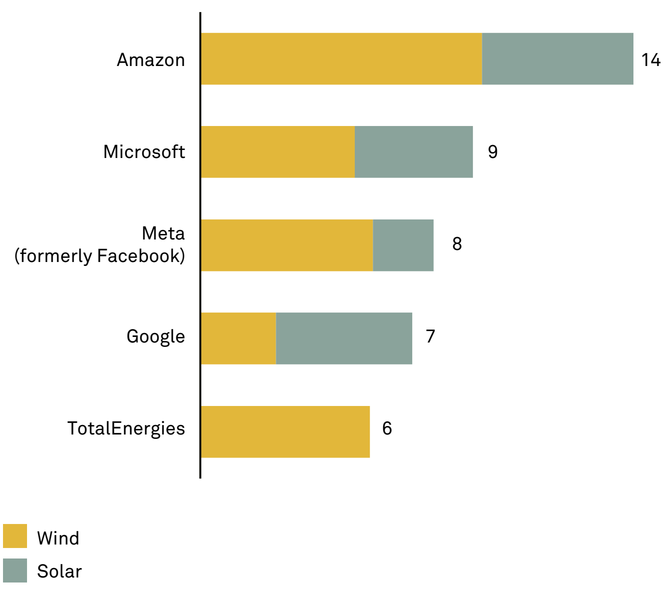
Many major technology companies have determined that it was not enough to purchase carbon-free energy through so-called unbundled carbon-free energy certificates (RECs), as this did not ensure additionality. Additionality is the notion that the carbon-free electricity purchased by a company is additional to that which already existed in the grid where the company operates. A company's carbon-free electricity purchase is considered additional if, in the absence of the company's involvement, this electricity would not have been generated.

Figure 19.

Global PPA volumes by sector, 2010-2021
GW



Top corporate off-takers of renewable PPAs, 2010-2021
GW



Note: Implement illustrations based on data from the IEA and BNEF.

Additionality has best been achieved through the use of PPAs and has been supplemented by other instruments like green electricity tariffs, especially in locations where PPAs have not been possible due to the legislative environment.

The tech sector has been the global leader in corporate power purchase agreements, accounting for 45% of all PPAs signed to date, including 49% of the record 31.1 GW signed in 2021. For context, this is roughly equivalent to the entire installed capacity of wind power in Canada.[99] This picture is also reflected in Europe, where the digital sector is also the leader in corporate PPAs, accounting for 35% of PPAs between 2013 and 2022.[100] Nearly all PPAs signed by the tech sector for carbon-free energy are for projects that are not yet constructed by the time the contract is signed, meaning they lead to additional carbon-free energy capacity deployed onto electricity grids.

Many tech companies are now moving beyond 100% annual carbon-free energy matching to focus on 24/7 carbon-free energy and decarbonise their electricity consumption every hour, everywhere. Google,[101] Microsoft,[102] and Iron Mountain[103] have all committed to achieve 24/7 CFE and are part of the global effort coordinated by Sustainable Energy for All and UN-Energy to advance solutions in this space.[104]

When tech companies match their energy consumption with yearly carbon-free energy purchases, they do not guarantee that their data centres run on carbon-free energy every hour of every day. Because of the intermittent nature of most renewable electricity generation from technologies like solar and wind power, there are hours without wind or solar power, but data centres cannot stop running.

The 24/7 CFE approach is the gold standard of sustainable operations, as it means that no carbon is emitted by the electricity supply used to power data centres.

Achieving this requires an entirely new strategy that takes into account when and where energy is generated and consumed. This requires innovations in clean energy purchasing and technology, as well as policy shifts. On the purchasing front, Google recently pioneered a new transaction structure called the CFE Manager, whereby an energy retail provider assembles a portfolio of technologies that can guarantee a minimum level of hourly clean energy matching.[105]

On the generation side, it requires investing in non-intermittent carbon-free generation technologies such as geothermal or hydropower, as well as combining different technologies that can complement each other (e.g., solar panels that produce energy during the day and wind turbines that take advantage of stronger winds at night). On the consumption side, it places a focus on energy storage and demand flexibility.

Google's actions towards 24/7 carbon-free electricity

In its pursuit of 24/7 CFE, Google is taking several steps:

- Investing in a next-generation geothermal plant to power its operations in Nevada, USA providing data centres and offices in the region with carbon-free power.[106]
- Installing a battery park at its data centre in St. Ghislain, Belgium, which will be used for backup as well as to help balance the Belgian grid.[107]
- Using AI applications to better match supply and demand. On the demand side, AI is applied to match data centres' workloads to the availability of carbon-free power.[108] On the supply side, AI is applied to improve the productivity of the geothermal plant while matching energy needs.[109]

Figure 20.

Google's batteries in St. Ghislain, Belgium:

In addition to advancing Google's CFE goals, these batteries will be used to help balance the Belgian grid.

Illustration of Google's geothermal project in Nevada, USA:

Google has recently invested in a next-generation geothermal plant to power its operations in Nevada, USA. It will provide Google's data centres and offices in the region with firm, carbon-free power.

Note: Implement's own illustration based on information from Google. Photo credits: Google.

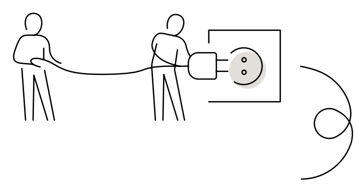
A large study for the European Commission estimated, with a noted degree of uncertainty, that EU data centres used around 80 TWh of electricity in 2018. The EU study has not been able to determine the corresponding greenhouse gas emissions but provides a rough estimate indicating that the data centre share of EU greenhouse gas emissions for the year 2018 was 0.4 to 0.6%. This corresponds to 15–20 MtCO_2e. The same study provides a trend forecast of the EU data centre electricity use with an increase of about 30% from 2018 until 2030, and scenarios ranging from a reduction in electricity use by 30% to an increase of 100%. Projecting these numbers with the expected decarbonisation of the grid (-60%) results in 2030 emissions from the EU data centre industry of between 6–18 MtCO_2e, depending on the scenario for electricity use. In all scenarios, the total emissions in 2030 are projected to be lower than current emissions, due to the decarbonisation of the grid.

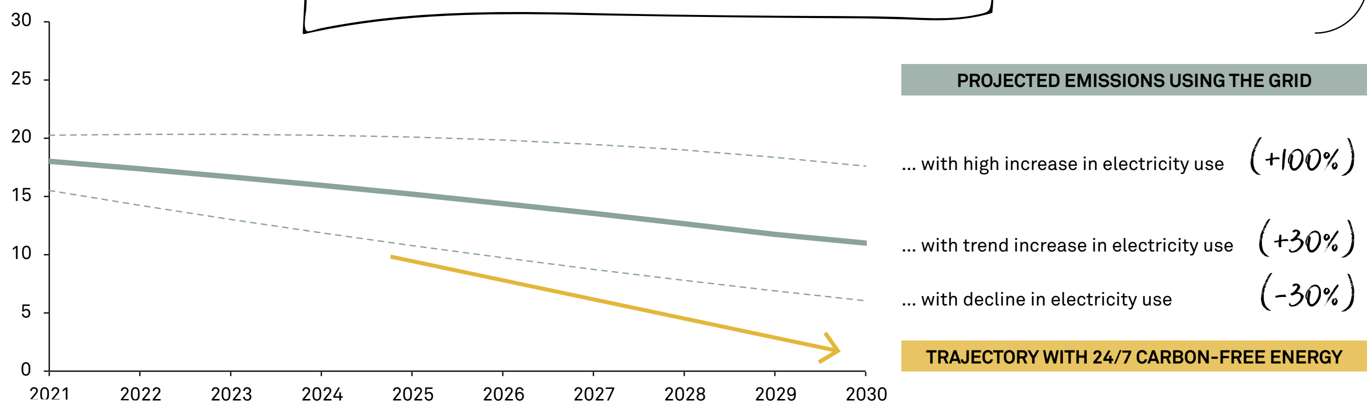
Figure 21.

Projected CO_2 emissions from European data centres
MtCO_2e

Method

- The European data centre electricity consumption is taken from the EU study by Montevecchi et al. (2020) which has three scenarios: high growth (+100%), trend growth (+30%) and one with decline in electricity use (-30%) due to efficiencies.
- The “Emissions using the grid” calculation is based on the assumption that all data centres take 100% of the electricity they use from the grid.
- The average carbon content of grid is the EU average, as reported by the EEA, which does not take the geographical distribution of European data centres into consideration. The projected decrease in the carbon content of the grid is also taken from the EEA.





Source: Implement analysis based on data from the EEA and Montevecchi et al. (2020).

This approach does not account for the carbon-free energy additions to the grid and load shifting made by the data centre operators, even though some Google data centres, for example, operate around 90% carbon-free energy on an hourly basis (see figure 15). While there is no data available on the hourly CFE% of the entire European data centre industry, there is large potential for emissions reductions if the entire industry followed the practice of industry leaders.

If all data centres were to achieve 24/7 carbon-free energy matching, the entire operational emissions of data centres would be eliminated, corresponding to about 6–18 MtCO_2e in 2030. Looking ahead, a joint commitment and drive by the entire data centre industry to truly decarbonise their operations with 24/7 carbon-free electricity will be the quickest pathway to a net-zero data centre industry, and such a choice would be essential for a sustainable industry in Europe.

3.4. Carbon neutral supply chains is the next step

Scope 3 represents the vast majority of most companies' greenhouse gas emissions, and the tech sector is no exception. For example, in 2021, scope 3 accounted for 99% of Meta's emissions,[110] 98% of Microsoft's,[111] and 84% of Google's.[112] Scope 3 encompasses emissions that occur in a company's value chain but outside of its operational boundaries. This includes upstream activities such as the mining, production and transport of inputs and downstream activities such as the delivery and operation of a company's products, as well as emissions generated by capital goods. For data centres, the bulk of scope 3 emissions stem from the manufacturing of IT equipment and the construction of the buildings that house them.

Although it represents the lion's share of most companies' emissions, scope 3 is very difficult to accurately measure and reduce. Because scope 3 emissions occur outside of companies' operational boundaries, firms must rely on an often large and diverse group of suppliers and service providers for data pertaining to them. It is common for figures to be derived from industry averages and to rely heavily on simplifying assumptions to compensate for the lack of accurate tracking and measurement. This leads to a high degree of variability in companies' baseline emissions.

The largely imprecise figures currently available for scope 3 emissions are useful to contextualise their relative importance but fail to provide an actionable way for companies to efficiently target and reduce them. If figures do not accurately reflect the reality of a particular company's value chain emissions, they do not allow that company to identify specific problem areas, nor do they reflect or incentivise actions taken to reduce the footprint of specific suppliers.

In the last two years, tech leaders have set ambitious targets for reducing scope 3 emissions. These include Google's commitment to achieve net-zero carbon along its entire value chain by 2030 and Microsoft's pledge to reduce its scope 3 emissions by more than half over the same period. These targets underline the sector's commitment to cutting emissions and will require significant efforts from all suppliers and service providers in addition to the tech industry itself.

The first step in tackling this challenge is to improve the collection and structuring of data, as well as updating reporting guidelines to reflect a change of focus from emissions disclosure to decarbonisation. Unlike disclosure, supply chain decarbonisation is an action-oriented goal that requires a precise and comprehensive overview of emissions along a company's value chain.

Tech companies can play an important role in setting up systems for data collection and processing, leveraging technologies like geospatial tracking and blockchain to radically improve companies' visibility of their value chains. These advancements will be crucial to create a reliable baseline for emissions, which will, in turn, allow companies to partner with their suppliers to target and reduce them.

By tackling their own value chain emissions, tech companies can radiate their impact in two important ways: firstly, by partnering with their own suppliers to reduce their emissions, which pushes the carbon reduction effort in related sectors such as steel and the manufacturing of electronic components; secondly, by developing the technologies and systems needed to enable all sectors of the economy to extend their decarbonisation efforts beyond the boundaries of their own operations.


THE
BUZZ

CHAPTER 4: Unlocking the potential

Policy conversations to advance the twin digital and green transformation in Europe

The report recommends the acceleration of digital decarbonisation and the decarbonisation of digital to further unlock the digital potential towards climate change mitigation

The twin digital and green transformation is high on the European policy agenda. The EU Council conclusions of December 2020 on Digitalisation for the benefit of the environment emphasised that the digital component will be key in reaching the ambitions of the European Green Deal and the Sustainable Development Goals (SDGs) as set out in the EU digital strategy.[113]

On the backdrop of recent geopolitical events and the resulting energy crisis, the European Commission, in its 2022 Strategic Foresight Report, recommends accelerating both transitions.[114] Several underpinning initiatives are ongoing, including the European Green Digital Coalition, which is a collaboration between digital companies led by the European Commission.[115]

Based on the findings of the report, we see two equally important priorities for the acceleration of the twin transition:

- **DIGITAL DECARBONISATION:** Maximising the enabling role of digital technologies by accelerating already available digital solutions at scale within four key sectors of the EU economy.

- **DECARBONISING DIGITAL:** Minimising the carbon emissions across the entire digital value chain by decarbonising all operational electricity emissions and addressing the embodied emissions.

These two priorities should be the key focus in the upcoming conversations between policy makers, business leaders and opinion formers. These policy priorities are described in the following sections.

Digital decarbonisation:

Maximising the enabling role of digital technologies by accelerating already available digital solutions at scale within four key sectors of the EU economy

The acceleration of the digitally enabled decarbonisation should focus on the top four sectors and can be structured around the three key ways in which digital can help:

- Making the transition to greener alternatives more affordable, convenient, and accessible via faster uptake of innovative digital technologies.
- Driving more with less by unlocking the potential for step changes in energy efficiency and productivity enabled by digital solutions.
- Promoting more sustainable alternatives where digital technologies can replace less sustainable activities.

The potential to be unlocked

Digital solutions are important enablers of affordable and cost-effective climate change mitigation at scale. For example, digital solutions are a critical enabler of demand flexibility in relation to the forthcoming doubling of electricity use in Europe towards 2050.[116]

The provision of real-time data to support a climate-friendly transport choice or a more climate-conscious heating behaviour in people's homes is a cost-effective way of decarbonising. So is the use of video conferencing when it can replace the need for a long business flight.

As shown in chapter 2, the report estimates that 20–25% (or 700–900 $MtCO_2e$) of the needed greenhouse gas reductions will require a degree of digital enablement. These potentials are within transportation, buildings, manufacturing, and agriculture. There is also a large potential for digital solutions in the power sector, but this is already being addressed as the European Commission is expected to publish an EU action plan for digitalising the energy sector.[117]

Policy gaps and recommendations

This report sees two policy areas to be addressed to accelerate the twin transition:

- Tapping into the potential for digital climate solutions in non-energy sectors.
- Policy framework for defining sustainable digital solutions.

To address the first point, this report suggests creating sector plans in partnership with key stakeholders. The second point requires a further strengthening of the cross-cutting policy framework.

Creating sector plans in partnerships

The next big thing that could be done to accelerate the twin transition and unlock the above potential could be to develop sector specific plans within sectors with the highest potential. Such sector plans should be co-created in close partnership between policy makers, business leaders, civil society and key opinion formers, for example inspired by the Climate Partnerships orchestrated by the Danish Government.[118]

These sector partnerships should identify barriers to the deployment of digital solutions and innovations enabling climate change mitigation within the specific sectors (e.g. transportation, buildings, manufacturing, agriculture, etc) and where such barriers prohibit or disincentivise the use of digital technologies, the partnership should propose actions to address and reduce such barriers.

The partnerships should also propose other policy initiatives for example around R&D, skills or infrastructure. The goals set out in the EU Digital Compass provides a good direction for this.[119]

To prioritise the efforts of such sector action plans in the spirit of the recent 2022 Strategic Foresight Report, it would make sense to give highest attention to the areas where digital solutions have the biggest potential to drive short-term energy savings and support the accelerated transition to electrical power.

This points towards two groups of digital solutions, which policies should focus on:

A. Electrification which is a key decarbonisation pathway (see use cases 1, 2, 3 and 13).

B. Energy efficiency effort, which can be accelerated by several digital solutions (see use cases 4 to 9 and 13, 14, 15,17, and 18).

The idea of sector plans builds on policy ideas proposed by Digital Europe, a trade association representing digitally transforming industries in Europe, proposing among eight policy ideas to create sector-specific action plans to facilitate the uptake of digital technologies across Europe's most energy intensive sectors.[120]

Strengthening the cross-cutting policy framework

To succeed with these sector plans and increase the uptake of digital climate solutions in an effective manner requires the completion of the policy framework. Digital entrepreneurs and digital businesses must have the legal certainty that is needed to make large and innovative investments in large scale operations of digital solutions which are often offered as cross-border supply of digital services. This will require an enabling policy framework that allows capital to flow effectively to where it is deployed most effectively.[121]

In this context, the on-going work by the EU Green and Digital Coalition to develop a commonly accepted method to measure the enabling contribution of digital solutions is crucially important. This will also be needed to use the EU Taxonomy in practice, and it is especially relevant for enabling activities such as digital solutions, which are activities that directly enable others to make a substantial contribution to an environmental objective.[122]

The lack of such indicators can result in lost opportunities for financing the development and deployment of green digital solutions. Widely different approaches can create internal market obstacles and it can hinder the procurement of green digital technology solutions by both public and private buyers.

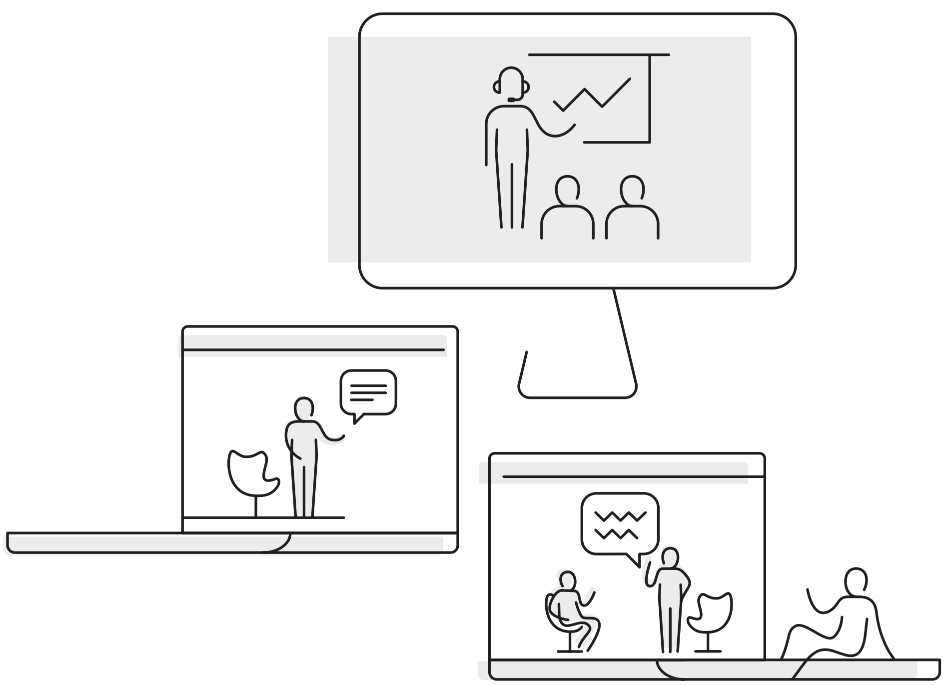
For these reasons the EU policy framework should be strengthened in the short term to provide a more coherent and enabling framework.

This will require:

- An alignment at the EU-level across the various policy initiatives on the definition of sustainable activities and activities enabling a significant contribution to climate change mitigation. The efforts of the European Green Digital Coalition towards this objective are important.

- Coherence between EU and national policy initiatives towards sustainable digital solutions to avoid barriers to the internal market for technologies enabling substantial contribution to environmental objectives.

- An external EU trade policy which also supports these objectives by promoting trade in digital services with positive enabling effects for the environment (see box).



Further strengthening the digital and green element in EU's external trade policy

Trade can support climate mitigation by increasing the availability of digital solutions and services enabling climate change mitigation. Promoting more cross-border trade and reducing trade barriers on such digital solutions will accelerate the diffusion of the most efficient solutions. For example, eliminating tariffs and non-tariff barriers on certain clean energy technologies and energy efficiency products could increase their trade volume by 14% and 60%, respectively. Specific rules promoting the trade of digital solutions that reduce carbon emissions are also likely to have a positive impact.

The EU's new trade policy An Open, Sustainable and Assertive Trade Policy is for the first time making sustainability an explicit and central pillar of trade policy. The trade policy review also aims at promoting the digital transition and trade in services. Trade policy more generally, such as bilateral trade or multilateral agreements, can be an important tool for the EU to promote high standards with its main trading partners and beyond. Digitalising trade can also help decarbonise trade itself, e.g. through more efficient goods trade or even substituting some of it. Many climate solutions depend on a wide range of supporting digital solutions. Increased electrification requires digital enablement such as smart charging, smart meters and advanced building solutions. Reductions in carbon emissions in the transport sector can be accelerated through efficient routing, avoiding longer routes, traffic jams and peak hours. European digital solutions should be exportable without trade barriers, just as the most efficient global climate solutions should be accessible to European users.

In summary, strong digital and environmental standards in EU trade policy can have a threefold effect on decarbonisation:

- Increase the availability of the most climate efficient technologies across the EU and globally, accelerating climate mitigation.
- Boost EU exports of climate enhancing digital tools, supporting the EU's economy.
- Further reduce the carbon impact of trade, in correlation with reductions in transport and agriculture.
- To ensure an enabling policy framework for the twin transition, EU's trade policy should also support these objectives by:
  - Promoting trade in digital services that are likely to have a positive impact on decarbonisation, also by addressing tariff and non-tariff barriers to such trade.
  - Supporting ongoing multilateral and bilateral efforts to facilitate trade in climate services by expanding them to trade in digital services.
  - Further study the role of trade in achieving sustainability goals.

Decarbonising digital:

Minimising the carbon emissions across the entire digital value chain by decarbonising all operational electricity emissions, and addressing the embodied emissions

In this report, we define the digital value chain as data centres, networks and devices. Decarbonising the entire digital value chain is an ambitious goal, which can be broken down into the following:

Operational emissions from electricity use

- **Data centres:** Data centres have operational emissions from their electricity use. These are typical large professional buyers of power, and 24/7 carbon-free electricity purchases would be the most effective approach.

- **Data transmission networks:** Networks also consume electricity on a global scale – more than data centres.[123] These are typical large professional buyers of power. Networks do not have the same load-shifting possibilities as data centres.

- **Devices:** Devices and terminals also use electricity and drive emissions. The end-users of digital services are businesses, public sector, and households. These are mostly retail electricity users.

Embodied emissions

- **Data centres:** Data centres are large buildings filled with servers and cooling equipment. These inputs used for producing digital services generate carbon emissions. As large professional buyers, data centres should be working with their suppliers to bring down so-called scope 3 emissions.

- **Data transmission networks:** Networks are both fixed and mobile networks, both of which generate carbon emissions. As large professional buyers, network operators should be working with their suppliers to bring down so-called scope 3 emissions.

- **Devices:** Devices and terminals also generate carbon emissions from their production. As buyers are mostly retail buyers of these devices, other measures need to be in place to address these emissions.

To advance towards the overall goal will require a concerted effort among policy makers, business leaders and consumers on several different policy dimensions.

In the following, we will present the high-level policies in these two main groups:

A. The emissions from electricity consumption (operational emissions).

B. The emissions from material use and other value chain emissions (embodied emissions).

Reducing operational emissions

In addressing the operational emissions from electricity use, it is important to distinguish between data centres and networks on one side, namely large professional buyers, and the electricity use of devices, which are typically from households and all types of small and large businesses, on the other side.

For devices, the main policy actions are to focus on energy efficiency of the devices and the on-going efforts to reduce the carbon content of the grid. These will not be addressed further here.

For data centres and networks, the EU has expressed that data centres and telecommunications will need to become more energy efficient and use more renewable energy sources and stated that they "can and should become climate neutral by 2030".[124]

As described in chapter 3 of the report, implementing a 24/7 carbon-free energy framework is vastly more effective in decarbonising the electricity supply than traditional annual matching of renewable energy when it comes to large buyers such as data centres.

A number of different policy initiatives could help underpin the decarbonisation of operational electricity emissions, including:

- **Accelerating carbon-free technology deployment.** Policy makers need to ensure that regulation and administration barriers do not prevent the swift deployment of sufficient carbon-free capacity, for instance through agile processes for approving and connecting new capacity – including also allocating offshore seabed to the vast expansion of foreseen offshore wind capacity. In addition, it is key to continue investments in the electricity transmission grid, in order to ensure that carbon-free energy can be delivered to where it is needed.

- **Providing companies and consumers with a better measurement of real decarbonisation.** Existing greenhouse gas accounting standards allow the use of yearly matching through Guarantees of Origin in order to fully reduce a company's emissions from electricity. As shown in this report, this is not fully accurate as 100% yearly matching will still be associated with carbon emissions being released from operations – something that could be avoided by using the 24/7 CFE framework. It is important to define solutions where consumers, companies and investors can distinguish whether a company's climate effort is relying on yearly matching or 24/7 CFE. One avenue is looking further into the possible value of time-based energy attribute certificates (T-EACs) that measure the climate impact on an hourly basis.

Reducing embodied emissions

Embedded emissions across the digital value chain contain a variety of different emission sources such as raw materials going into steel racks in data centres, and metals for electronic devices. As highlighted in the report, these emissions are likely to constitute a significant share of overall emissions related to the digital sector – while being very difficult to measure. Key policy initiatives to reduce these emissions include:

- Improved circularity in the digital sector through recycling, reusing, refurbishing and maintaining. Significant efforts are already in place within this agenda, and it is important to maintain momentum and ensure proper implementation of EU policy initiatives including the Circular economy action plan. Areas suggested in research are e.g. modular, standardised devices and systems to better allow repair, refurbishment and upgrading.[125]

- Improving efficiency of EU climate policies through e.g. the proposed cross-border adjustment mechanism. A significant share of upstream value chain emissions in the provision of digital services in the EU are likely being emitted outside of the EU. This would be true for an EU data centre rack relying on imported steel for example. Policy initiatives to provide better transparency on such emissions, including increased focus on disclosing such emissions.

DETAILED COLLECTION OF USE CASES

Transport | Do differently

Digital technologies supporting electrification of transport

Half of the emission reductions in transport relates to the electrification of cars, light trucks and city buses. The stock of electrical cars in the EU is expected to increase from around 2 million in 2020 to 30–50 million by 2030.[126] This is part of the expected doubling in total electricity use between now and 2030.

To ensure a socially acceptable cost of this massive electrification, it is crucial that EV charging becomes flexible and can adjust to electricity supply, so cars can be charged when the electricity is available and is greenest.

The following use cases all support this transformation.

- **Use case 1:** Demand flexibility with smart charging app for cars
  Objectives: Demand flexibility, electrification | Technology: Smart app | Sector: Transport

What are the effects

- An assessment of the Danish electrification (also a doubling) shows that the investment in grid infrastructure towards 2030 can be 28% lower with demand flexibility, i.e., when users (e.g., EVs) shift their consumption to times of the day when power supply is available.

- Research on the effects of smart charging in a sophisticated and digitally enabled form, which uses price signals, has shown that it is possible to effectively regulate EV charging rates to avoid grid congestion and achieve lower charging costs compared to normal charging. At the same time, it is possible to maintain user comfort, i.e., making the vehicle ready for the next trip with the desired level of charging at the preferred time. The research also found that smart charging reduced the cost of charging by a factor of two.[127]

How does it work

- The smart charging app is used to control the EV charging in people's driveways and ensure that the vehicle is charged by the time set by the EV owner (such as the next morning) and charged optimally during that period according to availability in the grid.

- The smart charging app is integrated with electricity price forecasts (a digital solution using big data and AI), thus helping the user to react to price signals.

- It can be charged with most climate-friendly energy, timing the charging with energy production expected from carbon-free energy sources.

- Smart charging allows the use of bidirectional charging, which is a sustainable solution that allows use of the car’s battery for storage, charging it when energy is cheaper and/or greener and using that energy when there are spikes in energy demand – pushing energy back to the grid (vehicle-to-grid, V2G) or to the home (vehicle-to-home, V2H).

What it looks like

- Monta app
- EV Energy app
- True energy
- Bidirectional smart charging, e.g. Wallbox

- **Use case 2:** Charging app for “on the road” charging
  Objectives: Electrification | Technology: Smart app | Sector: Transport

What are the effects

- A smart app for EV charging provides convenience and reduces “range anxiety” for EV users and thus supports the transition to EV broadly speaking.

How does it work

- Gives location of charging points and real-time availability of charging points.

- Provides payment interface with multiple suppliers of charging points allowing the Wuser to have a single interface for all charging regardless of supplier.

What it looks like

- Smart app
- PlugShare
- ChargePoint

- **Use case 3:** Smart energy management systems for new logistics hubs
  Objectives: Electrification | Technology: AI, smart energy management system | Sector: Transport

What are the effects

- Smart energy management systems are crucial for new logistics hubs such as the Amsterdam City Logistics Innovation Campus (CLIC) to electrify light trucks that can serve the city with supplies.

How does it work

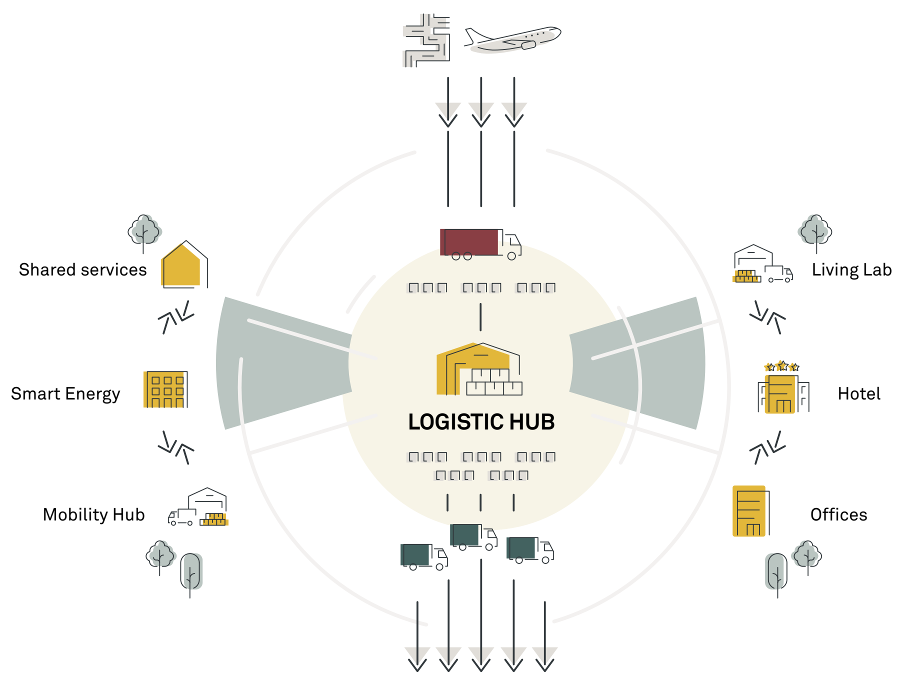
- The City Logistics Innovation Campus (CLIC) is a campus outside Amsterdam that provides mass EV charging to make city logistics emissions-free, as the city of Amsterdam is banning fossil-fuel cars from 2025.

- The electricity needed to operate the hub could not be provided by the current national grid if not for the smart energy management system that reduces capacity and optimises electricity use.

What it looks like

Figure 21

Logistic Hub



The impact: Electrification is expected to drive 40–50% of the reduction needed for CO_2 emissions from transport by 2050

The need for further electrification is significant. Analyses show that 40–50% of transport CO_2 emissions should be reduced through electrifying cars, light trucks and city buses which correspond to around 330 $MtCO_2e$ of 2020 emissions. Digital technology is an integrated part of the transformed and electrified transport system, along with other technologies (the electric vehicles, the charging infrastructure, the electricity grid).

Transport | Use less

Digitally enabled sustainable transport choices

A quarter of the emission reductions in transport is expected to come from energy efficiency.[128]

Digital technologies can help bring efficiencies by providing the right information to users to improve the sustainability of their transport choices.

The tech sector collects data, structures it and makes it accessible to users in an actionable manner. This enables lower-emissions decisions and nudges users towards lower-emissions behaviours.

The following use cases all support this transformation.

- **Use case 4:** Eco-routing nudging drivers to drive lower-emission routes
  Objectives: Energy efficiency | Technologies: Route optimisation software | Sector: Transport

What are the effects

- Eco-routing software can save fuel and reduce emissions per trip, by suggesting the most fuel-efficient route to drivers – both for passenger and freight transport.

How does it work

- Eco-routing suggests the most efficient route to the driver in order to save fuel and avoid congestion.

- The IEA estimated that eco-routing can save between 1% and 10% of emissions from freight trucks.[129] In collaboration with Google Cloud Platform, UPS designed eco-routing software that reduces fuel consumption by 10 million gallons a year (while also saving up to USD 400 million a year).[130]

- Google Maps now shows the most fuel-efficient route, if it is not also the fastest, allowing users to compare them. The team at Google estimated that eco-routing, since its introduction in the US and Canada, has helped remove more than 0.5 million metric tons of carbon emissions, equivalent to taking 100,000 fuel-based cars off the road.[131, 132]

- Moreover, the team at Google Maps in partnership with more than 10,000 local governments, transport agencies and organisations around the world, is able to reflect the latest information on Google Maps, including transit schedules, bike lanes and road closures.[133]

What it looks like

- Google Maps
- UPS and Google Cloud Platform

- **Use case 5:** Flight comparison platforms providing emission information
  Objectives: Energy efficiency | Technology: digital platform | Sector: Transport

What are the effects

- Showing emission information on flight booking platforms can nudge consumers towards booking flights with lower emissions, resulting in an overall emission reduction.

How does it work

- When searching for flights on a given route and date, the platform highlights the flights that for that route have lower emissions.

- This information is collected by Google based on route and carrier model.

What it looks like

- Google Flights
- Skyscanner

- **Use case 6:** Geolocation and satellite data for green infrastructure in cities
  Objectives: Green transport | Technology: digital platform, AI, geo location, satellite | Sector: Transport

What are the effects

- Geolocation and satellite data can provide accurate information on citizens' modes of transport, emissions in the city and space that can be dedicated to green infrastructure, such as bikes.

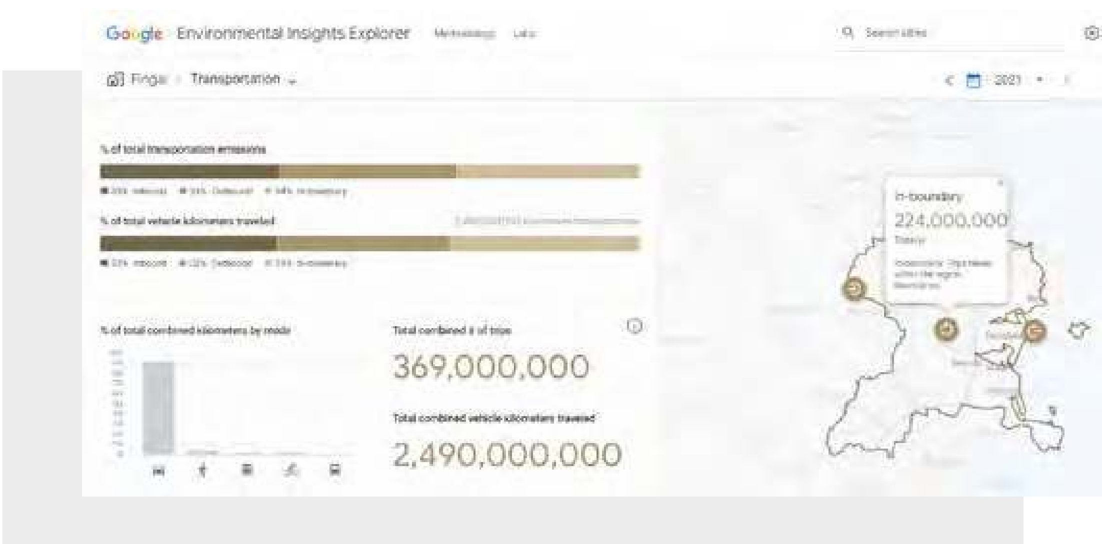
- Dublin City Council has been using Google's Environmental Insights Explorer (EIE) since 2019 to analyse bicycle usage across the city, implement smart transport policies that improve cycling infrastructure to reach the objective to increase the share of transport done via cycling,[134] and tracking their progress. Compared to 2018–2019, the city saw a 11% increase in bike trips and a 21% increase in km travelled.[135]

How does it work

- The City of Dublin has been using Google's EIE to improve its bike infrastructure. Google's Environmental Insights Explorer (EIE) was created to help cities around the world in their green transition, providing granular city-level climate data. EIE uses anonymised and highly aggregated data from Google Maps and Google Earth, combined with other data sources to create useful environmental insights for cities on buildings and transport emissions, the potential for rooftop solar panels, air quality for each street and the density of tree canopies.

- EIE allows cities to measure their environmental impact, plan their actions by running scenarios, take informed action, and track their progress through an easy interactive dashboard.

What it looks like



- **Use case 7:** Mobility as a Service nudging passengers towards greener transport
  Objectives: Energy efficiency, greener transport mode | Technology: MaaS platforms | Sector: Transport

What are the effects

- MaaS platforms can nudge users towards choosing more environmentally friendly modes of transport, reducing emissions per passenger, by presenting users with alternative transport options that have lower to no emissions (such as trains, electric scooters and bikes).

- MaaS solutions can also increase efficiency in mobility by connecting across transport modes and by improving the organisation of transport systems, reducing waiting times, congestion – and subsequently, emissions.

- The use of MaaS platforms can entail a rebound effect, if the platform e.g. facilitates transport by taxi.[136]

- The net effect depends on the awareness of climate impact by the passenger and on the policies in place. The city of Dublin case is a good example of digital technologies paired with a policy for moving towards greener transport.

- The European Commission's JRC study on green and digital transition, based on a simulation study,[137] reports that "if MaaS would totally replace individual private car usage, there could be a reduction in CO_2 emissions of over 50%".[138]

How does it work

- Mobility as a Service (MaaS) platforms refer to digital platforms that provide users with real time comparison of the available transport options for a given trip.

- MaaS platforms facilitate modal shift from private cars to public transport and non-polluting transport means (such as bikes and electric scooters). Google Maps is an example of a platform that shows real-time information on available transport modes such as bikes and electric scooters in 300 cities around the globe, allowing users to find nearby stations and pinpoint how many vehicles are available. This is done thanks to partnerships with providers such as Bird, Donkey Republic, Voi and Tier.[139]

- At the same time, Google Maps has announced a range of new cycling features to support the use of bikes, such as "lite" navigation, a way for cyclists to see important details about their route without needing to keep their screen on or enter turn-by-turn navigation.

What it looks like

- Green Mobility app for electric car use in cities
- Donkey Republic app for city bike rental
- Electric scooter apps, such as Bolt and Lime
- Taxi services, such as Lyft and Uber
- Google Maps suggesting different transport modes

- **Use case 8:** Ride sharing platforms optimising passenger load
  Objectives: Energy efficiency, load optimisation | Technology: digital platforms | Sector: Transport

What are the effects

- Ride sharing platforms optimise passenger loads by allowing multiple passengers to travel in the same car, reducing emissions per passenger.

- The use of ride sharing platforms can entail a rebound effect, if the a passenger chooses to travel by car instead of using a lower-emission mean such as bus or bike.[140]

- The net effect depends on the awareness of climate impact by the passenger and on the policies in place.

How does it work

- Ride sharing platforms (both centralised, such as Uber, and peer-to-peer, such as BlaBlaCar) enable a higher usage percentage of vehicles.

What it looks like

- Uber and Lyft allowing ride sharing.
- BlaBlaCar and GoMore facilitating drivers to transport more passengers.

- **Use case 9:** Digital technologies in freight transport
  Objectives: Energy efficiency, load optimisation | Technologies: Cloud, AI, Route optimisation, co-modality platform | Sector: Transport

What are the effects

- Digital technologies applied to heavy load trucks to improve energy efficiency and reduce fuel use can, individually, save up to 20% in energy consumption. The savings increase when multiple technologies are combined.[141]

- The Port of Rotterdam, with support from the Cisco Internet of Things (IoT) solution Edge Intelligence, is able to optimise route planning and ships' berthing, increasing fuel efficiency and reducing carbon emissions – being on track to reduce their carbon emissions by 50% in 2030.[142]

How does it work

- Eco-routing suggests the most efficient route to the driver in order to save fuel and avoid congestion.

- Systematic monitoring, collection and analysis of shipment operations, enabled by ICT (such as GPS and fleet management software) leads to improved vehicle utilisation.

- Collaboration across the value chain, or co-modality, is another way to optimise load enabled by ICT (through online freight exchanges or procurement platforms).

What it looks like

- GPS and fleet management software
- The European Union's CO3 Project on horizontal supply chain collaboration

The impact: Improved energy efficiency is expected to drive 20–25% of the needed reduction in CO_2 emissions from transport by 2050

The analyses show that 20–25% of transport CO_2 emissions should be reduced by increased energy efficiency of transport means, corresponding to 160 $MtCO_2e$ of 2020 emissions. Digital technology is a key enabler in optimising transport routes, modes, load and use of fuel and thus contributing to energy efficiency of transport.

Transport | Stop using

Digital technology replacing the need for transport

A smaller part of the emission reductions in transport is expected to come from reduced demand (5–10%), i.e. less travel and commuting.[143]

Digital technologies can help reduce the need for transport by offering digital alternatives making transport unnecessary.

The following use cases all support this part of the green transformation of transport.

- **Use case 10:** Digital solutions supporting increased working from home
  Objectives: Reduced demand | Technology: cloud, video conferencing, VR/AR | Sector: Transport

What are the effects

- The IEA has shown that the net effect of working from home one day saves 4.9 kg of CO_2 in summer and 3.1 kg of CO_2 in the winter, when taking into account that working from home saves transport emissions from commuting but increases home emissions from heating and electricity.[144]

How does it work

- Covid-19 created a step-change in the uptake and use of digital collaboration tools and video meetings.
- This increased the acceptance of working from home, and recent data shows that on average Europeans are working 1.6 more days per week from home than before Covid-19.
- Much of this increase in working from home is supported to a great extent by digital solutions.

What it looks like

- Google Drive and Google Meet
- Microsoft SharePoint and Microsoft Teams
- Miro boards
- Slack

The impact: 2–3% reduction of CO_2 emissions from car transport

We estimate that digital technologies allowing employees to work from home, such as cloud, online collaborative documents, video conferencing and virtual reality (VR)/ augmented reality (AR) tools are already today (post Covid-19) saving between 2–3% of car emissions which equals savings of 10–15 $MtCO_2e$ per year in the EU compared to 2020 emissions.[145, 146]

Transport | Stop using

Video conferencing replacing international flights

Carbon emissions from international flights are outside of the EU and national reduction targets and hence treated separately here.

The use of video conferencing experienced a large increase during the pandemic and part of this change is expected to be permanent. This means that digital solutions are already replacing international business travel and thereby avoiding the emissions that would otherwise have resulted.

- **Use case 11:** Video conferencing reducing business purpose air travel
  Objectives: Reduced demand | Technology: video conferencing, VR/AR, drones | Sector: Transport

What are the effects

- Between 20–25% of business travel is estimated to be replaced by video conferencing in 2022.[147]

How does it work

- Covid-19 has shown that many business meetings can be held remotely, avoiding travel, which often entails air transport.
- Video conferencing tools allow business meeting and conference attendance remotely.

What it looks like

- Google Meet
- Microsoft Teams
- Zoom

The impact: 4–6% reduction of CO_2 emissions from global air passenger transport

We estimated that digital technologies that allow participating in meetings and conferences remotely, such as video conferencing and virtual reality (VR)/ augmented reality (AR) tools are saving between 4% and 6% of global emissions from commercial passenger flights, which corresponds to a reduction of 30–50 $MtCO_2$ compared to 2019 levels.[148]

Buildings | Do differently

Applying digital technology to enable the transition to non-polluting energy alternatives[149]

- **Use case 12:** Matching electricity supply and demand through exploitation of thermal inertia in buildings
  Objectives: Cost-efficiency | Technology: Grid control of heating | Sector: Buildings

What are the effects for the environment

- Digital technologies can align the flexible parts of electricity demand from buildings with total demand and supply for electricity.

- This enables a more efficient and thus cheaper integration of the increasing electricity production from cost-competitive and sustainable, but variable, sources such as wind and solar.

How does it work

- When electricity production is too low, building control systems can exploit the temperature inertia by postponing heating, ventilation or air conditioning (HVAC). When there is excess energy production at a given time, HVAC can be applied in advance to reduce the energy consumption later.

- Research and products have been developed for building control systems and smart thermostats to be online and respond to a signal on when to postpone/advance electricity consumption based on electricity prices or direct signals from the grid controller, for example.

- Similarly, many appliances in buildings do not need to operate at a certain time. Examples are washing machines, tumble dryers and dishwashers, which can be flexible over several hours. Another example is fridges and freezers, which have thermal inertia so they can be switched off for a given time while keeping their contents at an acceptable temperature.

- Digital technologies can align the appliances' demand with real-time overall demand and supply in the electricity grid instead of a crude forecast.

What it looks like[150]

- InterFLex programme funded by the EU Horizon 2020.
- New technology such as the smart meter in combination with a powerful central management and control platform allowed the DSO to control flexible loads individually and directly.
- Avacon (DSO in Germany) steered residential loads (storage heaters and heat pumps) through its IT platform and E.ON (DSO in Sweden) directly controlled flexible assets in customer households.

The impact: Reduction of direct CO_2 emissions from buildings

- Demonstrated the effectiveness of flexible loads even under a simple demand response mechanism. The dynamic optimisation of daily charging cycles for storage heaters could improve DSO economics and potentially even lower distributed energy resource (DER) curtailments.
- Limiting heat pumps for short periods of time during peak demand could reduce stress on the network and improve the hosting capacity for growing segments such as EV.
- The potential reduction in DER curtailments could save millions of euros in lost generation.
- Advanced dynamic control mechanisms for flexible loads could likewise save on balancing costs and increase the hosting capacity for new customers.[151]

Buildings | Use less (machine action)

Applying digital technology to reduce direct emissions from buildings

- **Use case 13:** Reduced energy use in large buildings with artificial intelligence
  Objectives: Energy efficiency, CO_2 reductions | Technology: Artificial intelligence | Sector: Buildings

What are the effects for the environment

- Research shows that applying intelligent building control systems based on AI in large buildings reduces energy use by on average 20% to 40%, depending on the type of approach and without reducing comfort levels.[152]

How does it work

- Digital technologies automatically adjust heating, ventilation, and air conditioning (HVAC), while maintaining comfortable conditions.

- AI makes the system intelligent, so it reacts to feedback from users, thereby adapting more precisely to user needs.

What it looks like[153]

- Case study on a small building located in Pittsburgh, PA, USA, built in 2005, which has a typical office setup with meeting rooms and workstations. The building is equipped with a complex sensor network to measure and retrieve as much operational information as possible.

- AI is applied via a technology approach that includes the following modules: sensor network, building and system model, local weather forecasting, parameter estimation, occupancy detection, optimal control design and experiment setup.

- The results show that the heating energy consumption was saved by 30.1% compared with usual daily set-point and night set-back temperature control strategy.

- **Use case 14:** Reduced energy use in individual homes with smart thermostats
  Objectives: Energy efficiency, CO_2 reductions | Technology: Smart thermostats | Sector: Buildings

What are the effects for the environment

- Smarts thermostats reduce emissions in individual homes by reducing the energy consumption for heating, ventilation, and air conditioning (HVAC) by between 10% and 12%.[154]

How does it work

- Smart thermostats are a simpler and cheaper version of the automated and intelligent building control systems above, which makes them well suited for non-centrally controlled buildings and houses.

- Smart thermostats often replace very simple solutions such as manually controlled valves setting a fixed temperature.

What it looks like[155]

- Nest Learning Thermostat available for several years to retail consumers.

- The Nest Learning Thermostat is the first thermostat to get ENERGY STAR certified. It learns what temperature the user likes and builds a schedule.[156]

- Evaluated in numerous studies including one among Nest customers across 41 states in the US.

The impact: 5–6% reduction of direct CO_2 emissions from buildings

- Already today, artificial intelligence is deployed in large buildings and is saving around 1% of direct emissions from buildings corresponding to 2–5 $MtCO_2e$ of 2020 emissions.

- The potential for increased uptake is enormous. We estimate that artificial intelligence and smart thermostats can save 5–6% of direct CO_2 emissions from buildings towards 2050 corresponding to 25–30 $MtCO_2e$ of 2020 emissions if deployed at scale.[157]

Buildings | Use less (human action)

Applying digital technology to reduce direct emissions from buildings

- **Use case 15:** Reduced energy use in buildings with real-time data
  Objectives: Energy efficiency, CO_2 emissions | Technology: Real-time data | Sector: Buildings

What are the effects for the environment[159]

- Studies point to energy consumption behaviour in buildings being affected by access to real-time data on consumers' own consumption, resulting in a reduction of between 1% and 15%.
- In addition, utility-run energy-saving competitions and games in combination are found to have an impact between 0.4% and 14%.

How does it work

- By gathering and presenting CO_2 emissions data driven by different choices on energy consumption in buildings, digital technologies can stimulate less emitting behaviour.
- Through data, digital technologies enable the consumers to make choices to save energy with information they did not have before.

What it looks like[160]

- DTE Smartphone Insight App, which motivates users to save energy by providing near-real-time feedback on home energy use and weekly challenges for users.
- The app was tested for electricity and gas savings over the course of 6 to 17 months in three pilot studies that used matched controls and randomised encouragement designs.

The impact: Reduction of direct CO_2 emissions from buildings

- In these initial studies, energy savings were estimated at 1–3% for electricity and 2% for gas, after adjusting for savings by other utility programmes (among 7,000–9,000 users).[158]

Manufacturing | Use less

Applying digital technology to optimise the use of resources in manufacturing

- **Use case 17:** Energy savings through process optimisation
  Objectives: Energy saving | Technology: AI, IoT | Sector: Manufacturing

What are the effects for the environment

- Reduction in energy consumption, carbon emissions and water use.
- Estimates of the CO_2 reduction potential from using AI to optimise the manufacturing process and suggest system inefficiencies ranges between 5–10%,[161, 162] which amounts to a reduction of 36 $MtCO_2e$.

How does it work

- AI and IoT can be combined to monitor, predict and thereby suggest energy saving initiatives that maximise cost-savings without compromising production.
- Henkel, a German multinational chemical and consumer goods company, achieved a 10% reduction in CO_2 emission using sensors across production sites to provide feedback and real-time data to provide benchmarking (and 25% overall reduction in energy consumption).[163]
- Ericsson's factory in Lewisville, Texas has used advanced IoT sensors to monitor and reduce energy and water usage. The efficient design of the factory, combined with the use of these technologies has resulted in a 97% reduction in carbon emissions, as well as reductions of 14% in water consumption and 24% in electricity use relative to comparable factories.[164]
- Schneider Electric's factory in Lexington, Kentucky has combined the use of IoT with predictive analytics to reduce its energy use by 26%, water usage by 20% and to cut carbon emissions by 30%.[165]
- In partnership with Google, Renault has implemented an energy consumption dashboard that monitors energy use and suggests actions to reduce it. This has resulted in a 10–20% reduction in overall energy use.[166]

- **Use case 18:** Waste reduction through improved demand forecasting
  Objectives: Waste reduction | Technology: Machine Learning | Sector: Manufacturing

What are the effects for the environment[167]

- Demand forecasting powered by machine learning technologies can reduce waste and emissions across manufacturing.

How does it work

- In durable goods especially there is an overproduction to ensure product availability (e.g. 20% of clothes, and 33% of food are never sold). Using machine learning and big data can improve demand forecasting and thereby the inventory safety margin.

- By using demand forecasting, Nestlé was able to cut 14–20% of inventory safety stock.[168]

- Better demand forecast estimates suggest a 5–10 percentage point reduction in fashion industry production, which can reduce global fashion CO_2 emissions by 3–6% by 2030.[169]

Glossary

AI	Artificial Intelligence.
APAC	Asia-Pacific, the region of the world on the western Pacific Ocean.
AR	Augmented reality.
CFE	Carbon-free energy.
CLIC	City logistics innovation campus.
CO3	Carbon trioxide.
DC	Data centre.
DER	Distributed energy resources.
DSO	Distribution system operators.
DTE	DTE Energy, an energy company.
EC	European Commission.
EGA	Environmental Goods Agreement.
EIE	Environmental Insight Explorer.
ESG	Environmental, Social and Governance.
ETS	Emission trading scheme.
EU27	The European Union, consisting of 27 Member States.
EV	Electric vehicles.
E.ON	A European electric utility company based in Essen, Germany.
GDP	Gross domestic product.
GFW	Global Forest Watch.
GPS	Global positioning system.
GW	Gigawatt.
HVAC	Heating, ventilation, and air conditioning.
ICT	Information and communications technology, the convergence of computer, telecommunication, and governance policies for how information should be accessed, secured, processed, transmitted, and stored.
IoT	Internet of Things.
JRC	Join Research Centre.
MaaS	Mobility as a Service, a type of service that, through a joint digital channel, enables users to plan, book and pay for multiple types of mobility services.
ML	Machine learning.
$MtCO_2e$	Million tonnes of carbon dioxide equivalent.
PPAs	Power purchase agreements.
PUE	Power usage effectiveness, a metric used to measure the energy efficiency of a data centre's facility. It is the ratio between total energy used and energy used for IT equipment. A PUE value of 1 is a perfect score, which means all the energy used by the data centre is being used by IT equipment rather than facility operations like cooling and power provision.
RE	Renewable energy, i.e. energy resources that are cyclic and naturally replenished in some time intervals.
RECs	Renewable energy certificates.
REPowerEU	A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition.
R&D	Research and development.
TWh	Terawatt-hour.
VR	Virtual reality.
V2G	Vehicle-to-grid.
V2H	Vehicle-to-home.
WTO	World Trade Organisation.

Endnotes

1 REPowerEU plans for an additional electricity infrastructure investment of EUR 29 billion, on top of the investments estimated at EUR 536 billion between 2020 and 2030 required to reduce greenhouse gas emissions by 55%.

2 European Commission (2020). Sustainable and Smart Mobility Strategy – putting European transport on track for the future. COM (2020) 789 final. For comparison, in 2021 there were around 2.1 million passenger cars and vans with electric batteries within the EU.

3 Cf. EU Taxonomy paragraph 9. Public Office of the European Union (2020). Regulation (EU) 2020/852 of the European parliament and of the council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

4 A general purpose technology or GPT is defined as a new method of producing and inventing that is important enough to have a protracted aggregate impact; see for example Helpman E. (1998). General Purpose Technology and Economic Growth. Electricity and information technology (IT) are two prominent examples of a general purpose technology. GPTs have the potential to drastically alter societies through their impact on existing economic and social structures. Other examples include the steam engine and railways.

5 See the EU Taxonomy, article 16, which further states that this is the case provided such economic activity does not lead to a lock-in of assets that undermine long-term environmental goals, considering the economic lifetime of those assets, and has a substantial positive environmental impact on the basis of life-cycle considerations.

6 Cf. Article 10 (2) of the EU Taxonomy. Public Office of the European Union (2020). Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

7 Cf. EU Taxonomy, paragraph 40. Public Office of the European Union (2020). Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

8 Smart charging refers to the monitoring, management and control of electric vehicle charging stations and home charging with the goal of optimising energy consumption. Smart charging solutions compile charging data to better understand user charging profiles, essentially helping understanding of how customers charge their vehicles. A smart charging algorithm is typically used to help maintain a stable and balanced power grid by dispersing charging demand, which also allows consumers to charge at lower costs when energy demand is lower. This aggregation of power demand enables the system to maximise the use of renewable energies when they are available.

9 GeSI and Accenture (2015), #SMARTer2030 ICT Solutions for 21st Century Challenges.

10 GeSI and Accenture (2015), #SMARTer2030 ICT Solutions for 21st Century Challenges.

11 India Times (2021). Google's AI-Based Flood Forecasting System Is Saving Lives In India: Here's How. Retrieved September 13, 2022 from https://www.indiatimes.com/technology/news/google-ai-based-flood-forecasting-india-553906.html.

12 Nasa, Jet Propulsion Laboratory, Ocean surface topography from space. Retrieved September 21, 2022 from https://sealevel.jpl.nasa.gov/.

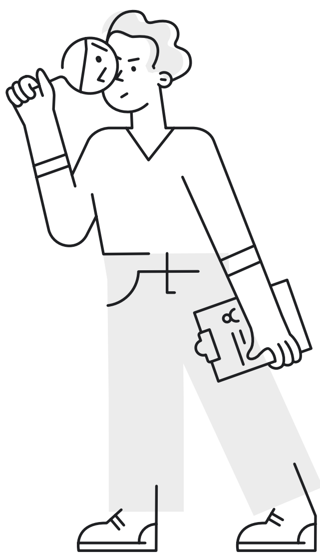
13 Google blog. Seeing through the smoke. Retrieved September 13, 2022 from https://about.google/stories/wildfire-safety-innovation/.

14 Google blog (2019). A new app to map and monitor the world's freshwater supply. Retrieved September 13, 2022 from https://www.blog.google/products/earth/new-app-map-and-monitor-worlds-freshwater-supply/.

15 NASA, Jet Propulsion Laboratory, Measuring Earth's Surface Mass and Water Changes. Retrieved September 21, 2022 from https://grace.jpl.nasa.gov/.

16 SPARC. Retrieved September 21, 2022 from http://www.sparc-website.org/.

17 Google blog (2016). Earth Engine creates a living map of forest loss. Retrieved September 13, 2022 from https://sustainability.google/progress/projects/forest-watch/.



18 Unilever news (2020). How Google will help end deforestation in our supply chain. Retrieved September 13, 2022 from https://www.unilever.com/news/news-search/2020/how-google-will-help-end-deforestation-in-our-supply-chain/.

19 Google blog. Is it possible to save a rainforest by listening to it?. Retrieved September 13, 2022 from https://about.google/stories/rainforest/.

20 Finansministeriet (2022). Ny digitaliseringsstrategi sætter retningen for Danmarks digitale fremtid. Retrieved September 20, 2022 from https://fm.dk/nyheder/nyhedsarkiv/2022/maj/ny-digitaliseringsstrategi-saetter-retningen-for-danmarks-digitale-fremtid/.

21 The project is supported by Google.org. See: Materiom (n.d.). We're growing the regenerative materials economy. Retrieved September 14, 2022 from https://materiom.org/.

22 The circularity of the tech sector itself is not part of this study. In this space, Google has taken steps to ensure the use of computing equipment along a circular approach, by maintaining, refurbishing, and reusing equipment. Source: Google (2019). Google Environmental Report 2019.

23 IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris https://www.iea.org/reports/data-centres-and-data-transmission-networks.

24 The IEA estimates that data centres and networks account for around 0.6% of global GHG emissions and around 2-3% of global electricity use. The IEA does not split the CO2-emission between data centres and networks, but they are reporting an energy use of 260-340 TWh for networks and 220-320 TWh for data centres. Based on the split of energy used, data centres are a little less than half of the combined network and data centre aggregate. See IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris https://www.iea.org/reports/data-centres-and-data-transmission-networks. For comparison, the much broader ICT sector is estimated to account for 5-9% of global electricity use and around 3% of global GHG emissions. See European Commission. Communication from the Commission to the European Parliament and the Council: 2022 Strategic Foresight Report Twinning the green and digital transitions in the new geopolitical context. Retrieved September 26, 2022, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0289&from=EN.

25 IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris https://www.iea.org/reports/data-centres-and-data-transmission-networks.

26 Implement calculation based on IEA (2022) (see) and International Telecommunication Union (2020). Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement. Geneva: ITU. Retrieved September 26, 2022, from https://www.itu.int/rec/T-REC-L.1470-202001-I/en.

27 VHK; Viegand Maagøe. (2020). ICT Impact Study. European Commission. Retrieved from https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2020-11/IA_report-ICT_study_final_2020_(CIRCABC).pdf

28 European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Stepping up Europe's 2030 climate ambition. COM (2020) 562 final.

29 European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Stepping up Europe's 2030 climate ambition. COM (2020) 562 final.

30 European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Stepping up Europe's 2030 climate ambition. COM (2020) 562 final.

31 Perasso, E., Vateau, C., & Domon, F. (2022). Evaluation environnementale des équipements et infrastructures numériques en France. Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse; Agence de la Transition Ecologique. Retrieved from https://www.arcep.fr/uploads/tx_gspublication/etude-numerique-environnement-ademe-arcep-volet02_janv2022.pdf

32 EU data from EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 8, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18. Global data from IMF Climate Change Dashboard. Retrieved September 22, 2022 from https://climatedata.imf.org/pages/re-indicators.

33 European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – Stepping up Europe's 2030 climate ambition. COM (2020) 562 final.

34 European Environment Agency (2021). Trends and projections in Europe 2021. EEA Report No. 13/2021.

35 The Digital Economy and Society Index (DESI) measures the digital performance of each country with a range of indicators related to digital skills, digital connectivity, uptake of digital technology by businesses and the use of digital in the public sector. See more at: https://digital-strategy.ec.europa.eu/en/policies/desi.

36 Equivalent to 803 MtCO2. Source: Statista (2021), Total emissions of carbon dioxide (CO2) in the member states of the European Union (EU) in 2019 (in million metric tons). Retrieved September 21, 2022 from https://www.statista.com/statistics/789024/emissions-co2-dioxide-of-carbon-by-country-eu/.

37 Because of the integrated role of digital solutions in the large-scale electrification, we have assessed that all of this potential will require some degree of digital enablement.

38 Based on the specific evidence from the use cases, we have assessed that half of the energy efficiency potential in transportation and buildings requires some degree of digital enablement.

39 Based on the findings from the use cases, we have assessed that half of the demand reduction potential in transportation and buildings requires some degree of digital enablement.

40 European Commission (2020). Sustainable and Smart Mobility Strategy – putting European transport on track for the future. COM (2020) 789 final.

41 BloombergNEF (2022). Europe's path to clean energy: A $5.3 trillion investment opportunity. Retrieved August 23, 2022 from https://about.bnef.com/blog/europes-path-to-clean-energy-a-5-3-trillion-investment-opportunity/.

42 BloombergNEF (2022). Europe's path to clean energy: A $5.3 trillion investment opportunity. Retrieved August 23, 2022 from https://about.bnef.com/blog/europes-path-to-clean-energy-a-5-3-trillion-investment-opportunity/.

43 See e.g. X.Tapestry – Weaving together the technologies, information, and partners needed for clean, reliable, and affordable electricity. Retrieved September 14, 2022 from https://x.company/projects/tapestry/.

44 Danish Government, Climate Partnership for Energy and Utilities (2020). Sektorkøreplan for energi- og forsyningssektorens bidrag til 70%-målsætningen.

45 EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 3, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18.

46 EC (2022). The European Green Deal. Retrieved September 8, 2022 from https://www.consilium.europa.eu/en/policies/green-deal/.

47 EC (2022). Fit for 55. Retrieved September 8, 2022 from https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/.

48 EC (2020). Sustainable and Smart Mobility Strategy. Retrieved September 8, 2022 from https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy_en.

49 Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., (2022) Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union.

50 EC (2020). Sustainable and Smart Mobility Strategy. Retrieved September 8, 2022 from https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy_en.

51 Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., (2022) Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union.

52 EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 3, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18.

53 EEA (2021). Greenhouse gas emissions from energy use in buildings in Europe. Retrieved September 8, 2022 from https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emissions-from-energy/assessment.

54 European Commission (2021). Revision of the Energy Performance of Buildings Directive. Retrieved September 8, 2022 from https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_6686.

55 EEA (2021). Greenhouse gas emissions from energy use in buildings in Europe. Retrieved September 8, 2022 from https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emissions-from-energy/assessment.

56 European Commission, Renewable energy targets. Retrieved September 21, 2022 from https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en#:~:text=The%202030%20targets,-Building%20on%20the&text=The%20Commission%20presented%20Europe's%20new,overall%20energy%20mix%20by%202030. Chestney, N. (2021). EU unveils plan to increase renewables share in energy mix to 40% by 2030. Reuters. Retrieved September 8, 2022 from https://www.reuters.com/business/environment/eu-unveils-plan-increase-renewables-share-energy-mix-40-by-2030-2021-07-14/#:~:text=To%20help%20meet%20the%202050,from%20roughly%2020%25%20in%202019.

57 Digital Europe (2021). Digital action climate action – 8 ideas to accelerate Europe's twin transition.

58 Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., (2022) Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union.

59 EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 3, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18. Note: Manufacturing emissions only cover direct emissions from chemical process, fuel combustion etc., and not indirect from e.g. consumption of electricity on the grid, see IPCC (1996). Guidelines for National Greenhouse Gas Inventories: Reporting Instructions.

60 The EU ETS target covers manufacturing, aviation and electricity and heat production. European Commission, see European Commission. Revision for phase 4 (2021–2030). Retrieved September 14, 2020 from https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/revision-phase-4-2021-2030_en.

61 D'Aprile, P. et al. (2020). Net-Zero Europe – Decarbonization pathways and socioeconomic implications.

62 EEA (2022). National emissions reported to the UNFCCC and to the EU GUnilever. Deforestation-free supply chain. Retrieved September 8, 2022 from https://www.unilever.com/planet-and-society/protect-and-regenerate-nature/deforestation-free-supply-chain/.

63 European Commission, Eco-innovation Action Plan (2021). Green and digital "twin" transition also spurs inclusive "eco-recovery" mindset in waste management. Retrieved September 8,2022 from https://ec.europa.eu/environment/ecoap/about-eco-innovation/policies-matters/green-and-digital-twin-transition-also-spurs-inclusive-eco_en.

64 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

65 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

66 Google Cloud, Inside Industry Data Management 4.0 at Renault. Retrieved September 20, 2022 from https://showcase.withgoogle.com/renault/.

67 GFA & McKinsey & Company (2020). Fashion on climate – How the fashion industry can urgently act to reduce its greenhouse gas emissions.

68 EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 3, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18.

69 EEA (2020). Water use by sectors. Retrieved September 12, 2022 from https://www.eea.europa.eu/archived/archived-content-water-topic/water-resources/water-use-by-sectors#:~:text=The%20main%20water%20consumption%20sectors,two%2Dthirds%20of%20total%20abstraction.

70 European Commission (2019), Agriculture and the Green Deal. Retrieved September 8, 2022 from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/agriculture-and-green-deal_en.

71 By 2050 compared to 2012 values, in terms of crop yield and livestock, see FAO (2018). The future of food and agriculture – Alternative pathways to 2050. Retrieved September 8, 2022 from https://www.fao.org/global-perspectives-studies/food-agriculture-projections-to-2050/en/.

72 See for example, OECD (2022). OECD Business Innovation Indicators.

73 Zhao C. et al. (2017). Temperature increase reduces global yields of major crops in four independent estimates. Retrieved September 14, 2022 from https://doi.org/10.1073/pnas.1701762114.

74 VivaTech (2022). HOW WOULD YOU "SOLVE" AGRICULTURE?. Retrieved September 12, 2022 from https://app.vivatechnology.com/onlinesession/a3c6c052-d9e7-ec11-b656-a04a5e7d2a9d.

75 Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., (2022) Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union.

76 X, the moonshot factory (2022). Uncovering the hidden magic of beans with X's Project Mineral. Retrieved September 12, 2022 from https://www.youtube.com/watch?v=DlwAqI3vybo.2022 from https://doi.org/10.1073/pnas.1701762114.

77 Digital Europe (2021) Digital action = Climate action: 8 ideas to accelerate the twin transition. Retrieved from https://www.digitaleurope.org/resources/digital-action-climate-action-8-ideas-to-accelerate-the-twin-transition.

78 X (2020). Mineral – Embracing nature's diversity to nourish generations to come. Retrieved September 8, 2022 from https://x.company/projects/mineral/#.

79 Malmodin, J. and P. Bergmark (2015), Exploring the effect of ICT solutions on GHG emissions in 2030, paper for 29th International Conference on Informatics for Environmental Protection, EnviroInfo 2015 (Ericsson Research).

80 See World Economic Forum (2022). Accelerating Decarbonization through Trade in Climate Goods and Services.

81 World Economic Forum (2022). Accelerating Decarbonization through Trade in Climate Goods and Services.

82 When asked about the "completeness" of the Internal Market in terms of the four freedoms, CEOs in the EU on average rated the Internal Market as being 75% complete. The Single Market for goods is 79% complete, whereas the Single Market for services is only 66% complete.

83 European Commission (2021). Trade Policy Review – An Open, Sustainable and Assertive Trade Policy. Retrieved September 8, 2022 from https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_645.

84 For a description of the digital chapters in EU trade deals see European Commission, Digital Trade. Retrieved September 21, 2022 from https://policy.trade.ec.europa.eu/help-exporters-and-importers/accessing-markets/goods-and-services/digital-trade_en.

85 Office of the United States Trade Representative (2017), Key Barriers to Digital Trade. Retrieved September 21, 2022 from https://ustr.gov/about-us/policy-offices/press-office/fact-sheets/2017/march/key-barriers-digital-trade; Digital Europe (2022), Single Market barriers continue limiting the EU's potential for the twin transition: examples in key sectors. Retrieved September 21, 2022 from https://www.digitaleurope.org/resources/single-market-barriers-continue-limiting-the-eus-potential-for-the-twin-transition/.

86 ENERDATA (2022). Global Energy & Climate Trends 2022. Webinar slides June 28th.

87 IEA (2017). Digitalisation and Energy.

88 IEA (2021). Data Centres and Data Transmission Networks.

89 An overview of Google's 24/7 energy is available at https://sustainability.google/progress/energy/. A further introduction to Google's approach to 24/7 carbon-free energy is available at https://www.gstatic.com/gumdrop/sustainability/24-7-explainer.pdf and the methodologies and metrics are available at https://www.gstatic.com/gumdrop/sustainability/24x7-carbon-free-energy-methodologies-metrics.pdf.

90 More information available at: Go Carbon-free 24/7. Join the Movement for a 24/7 Carbon-Free Energy Future. Retrieved September 14, 2022 from https://gocarbonfree247.com/.

91 Qingyu Xu, Aneesha Manocha, Neha Patankar, Jesse Jenkins (2021), System-level Impacts of 24/7 Carbon-free Electricity Procurement, Princeton University, Zero-carbon Energy Systems Research and Optimization Laboratory (ZERO Lab), November 16, 2021. Accessible at: https://acee.princeton.edu/24-7/.

92 See https://www.tu.berlin/en/about/profile/press-releases-news/2022/mai/carbon-free-energy-every-hour-of-every-day.

93 IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris. Retrieved September 26, 2022, from https://www.iea.org/reports/data-centres-and-data-transmission-networks

94 IEA (2022), Data Centres and Data Transmission Networks, IEA, Paris. Retrieved September 26, 2022, from https://www.iea.org/reports/data-centres-and-data-transmission-networks

95 Implement calculations based on data from: IEA (2021). Data Centres and Data Transmission Networks. Retrieved September 8, 2022 from https://www.iea.org/reports/data-centres-and-data-transmission-networks.

96 Masanet, E. et al. (2020). Recalibrating global data centre energy-use estimates. Science, 367(6481), 984–986.

97 B. Wagner (2018). Intergenerational energy efficiency of Dell EMC PowerEdge servers.

98 Shehabi, A. et al. (2016). United States data centre energy usage report. Lawrence Berkeley National Laboratory, LBNL-1005775.

99 Canadian Renewable Energy Association. By The Numbers. Retrieved 28 September, 2022, from https://renewablesassociation.ca/by-the-numbers/

100 European Platform for Corporate Renewable Energy Sourcing. Retrieved September 26, 2022, from https://resource-platform.eu/buyers-toolkit/

101 Google Sustainability. Operating on 24/7 Carbon-Free Energy by 2030. Retrieved August 22, 2022 from https://sustainability.google/progress/energy/.

102 Microsoft (2022). 2021 Environmental Sustainability Report, page 24.

103 Iron Mountain (2022). Powering towards leadership in clean energy. Retrieved September 14, 2022 from https://www.ironmountain.com/about-us/news-and-stories/stories/2022/january/powering-toward-leadership-in-clean-energy-a-look-at-our-data-centers.

104 Go Carbon-free 24/7. Join the Movement for a 24/7 Carbon-Free Energy Future. Retrieved September 14, 2022 from https://gocarbonfree247.com/.

105 Gstatic (2022). The CFE Manager: A New Model for Driving Decarbonization Impact. Retrieved September 8, 2022 from https://www.gstatic.com/gumdrop/sustainability/2022-carbon-free-energy-manager.pdf.

106 Terrell, M. (2021). "With new geothermal project, it's full steam ahead for 24/7 carbon-free energy". Retrieved September 6, 2022 from https://cloud.google.com/blog/products/infrastructure/google-fervo-geothermal-project-creates-carbon-free-energy.

107 Oman, M., & Fernandez Stearns, I. (2022). Clean Energy Projects begin to power Google Data Centers. Retrieved September 6, 2022, from https://cloud.google.com/blog/topics/sustainability/clean-energy-projects-begin-to-power-google-data-centers.

108 Radovanovic, A. (2020). Our data centers now work harder when the sun shines and wind blows. Retrieved September 6, 2022, from https://blog.google/inside-google/infrastructure/data-centers-work-harder-sun-shines-wind-blows/.

109 Terrell, M. (2021). "With new geothermal project, it's full steam ahead for 24/7 carbon-free energy". Retrieved September 6, 2022 from https://cloud.google.com/blog/products/infrastructure/google-fervo-geothermal-project-creates-carbon-free-energy.

110 Meta (2022). 2021 Sustainability report.

111 Microsoft (2022). 2021 Environmental Sustainability Report.

112 Google (2022). Environmental Report 2022.

113 See Council of the EU (2020), conclusions on Digitalisation for the benefit of the environment, 17 December 2020. Available at: https://www.consilium.europa.eu/en/press/press-releases/2020/12/17/digitalisation-for-the-benefit-of-the-environment-council-approves-conclusions/

114 See European Commission (2022), "Strategic Foresight Report: Twinning the green and digital transitions in the new geopolitical context", COM/2022/289 final.

115 The European Green Digital Coalition (EGDC) is a group of companies committed to supporting the green and digital transformation of the EU. The EGDC seeks to promote the development and deployment of green digital solutions with significant energy and material efficiency that achieve a net positive impact in a wide range of sectors, develop methods and tools to measure the net impact of green digital technologies on the environment and climate. See more at: https://digital-strategy.ec.europa.eu/en/policies/european-green-digital-coalition.

116 To illustrate, calculations from Denmark show that the cost of expanding the electricity grid and the renewable generation capacity can be 28% lower if demand can be shifted in time of the day to match supply. See Danish Government, Climate Partnership for Energy and Utilities (2020). Sektorkøreplan for energi- og forsyningssektorens bidrag til 70%-målsætningen.

117 See Digitalising the energy sector – EU action plan, accessible at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13141-Digitalising-the-energy-sector-EU-action-plan_en.

118 See more at https://climatepartnerships2030.com/.

119 See https://futurium.ec.europa.eu/en/digital-compass.

120 See https://www.digitaleurope.org/news/digital-can-cut-a-fifth-of-carbon-emissions-by-2030-heres-how/.

121 See also the 2022 Strategic Foresight Report page 14 saying: "The EU will need to leverage additional private and public long-term investments in twinning, especially in R&I across critical technologies and sectors, uptake and synergies between technologies, human capital, and infrastructures. This requires an enabling framework". See European Commission (2022), "Strategic Foresight Report Twinning the green and digital transitions in the new geopolitical context", COM/2022/289 final.

122 See Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

123 The IEA estimates global data centre energy use at 220-320 TWh in 2021 and global data transmission network energy use at 260-340 TWh in the same year, see https://www.iea.org/reports/data-centres-and-data-transmission-networks.

124 See European Commission (2020), Shaping Europe's Digital Future, page 7.

125 See for example ECERA (2020), White paper, Digital circular economy as a cornerstone of a sustainable European industry transformation.

126 IEA (2022). Global EV Data Explorer. Retrieved September 14, 2022 from https://www.iea.org/articles/global-ev-data-explorer; European Commission (2020). Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Sustainable and Smart Mobility Strategy – putting European transport on track for the future. Retrieved September 14, 2022 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789; Virta (2022). Global electric vehicle market overview in 2022: Statistics & forecasts. Retrieved September 14, 2022 from https://www.virta.global/en/global-electric-vehicle-market.

127 Martinenas, S. et al. (2015). Electric vehicle smart charging using dynamic price signal. IEEE International Electric Vehicle Conference.

128 D'Aprile, P. et al. (2020). Net-Zero Europe – Decarbonization pathways and socioeconomic implications.

129 IEA (2017). The Future of Trucks – Implications for Energy and the Environment.

130 Kurian, T (2019). UPS uses Google Cloud to build the global smart logistics network of the future. Google Cloud Blog. Retrieved September 6, 2022 from https://cloud.google.com/blog/topics/customers/ups-uses-google-cloud-to-build-the-global-smart-logistics-network-of-the-future.

131 The impact is estimated by Google, with the help of the U.S. Department of Energy's National Renewable Energy Laboratory's (NREL) RouteE technology, by "analysing the fuel consumption for all routes driven on Google Maps during the last year using a representative set of vehicle types. Then, using AI and Google Maps' record of available alternative routes at the relevant times, [the team at Google] identified and calculated the fuel usage of each of these viable alternative routes. This enabled [the team] to pinpoint the most fuel-efficient route for any given journey made last year. Next, [they] removed any fuel-efficient alternative that noticeably increased drive time or did not provide meaningful fuel savings. And finally, […] [they] tallied the total fuel usage of the more fuel-efficient routes, subtracting this number from the fuel usage that actually occurred, and input this value into EPA's Greenhouse Gas Equivalencies Calculator".

132 Google blog (2022). More ways to drive sustainably and save money with Google Maps. Retrieved September 19, 2022 from https://blog.google/around-the-globe/google-europe/eco-friendly-routing-in-europe/.

133 Google blog (2020). How 15 years of mapping the world makes Search better. Retrieved September 19, 2022 from https://blog.google/products/maps/15-years-of-mapping-the-world-makes-search-better/.

134 Dublin City Council (n.d.). Dublin City Development Plan 2016–2022 – Cycling. Retrieved September 14, 2022 from https://www.dublincity.ie/dublin-city-development-plan-2016-2022/8-movement-and-transport/85-policies-and-objectives/8541-cycling.

135 Bian, C. et al. (2021). With four years of mobility data, EIE is helping cities transition to sustainable transport. Retrieved September 12, 2022 from https://medium.com/google-earth/eie-2021-transport-1e3f0fdb4624-7acbd9bc0e95.

136 See for example Noussan, M. & Tagliapietra, S. (2020). The effect of digitalization in the energy consumption of passenger transport: An analysis of future scenarios for Europe.

137 ITS4Climate. (2019). Mobility as a Service for Climate (MaaS4C).

138 Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M. and Scapolo, F., (2022) Towards a green and digital future, EUR 31075 EN, Publications Office of the European Union.

139 Implement Consulting Group, based on interview with Google team.

140 See for example Noussan, M. & Tagliapietra, S. (2020). The effect of digitalization in the energy consumption of passenger transport: An analysis of future scenarios for Europe.

141 This is based on IEA (2017). The Future of Trucks Implications for energy and the environment of potential CO2 emissions reductions from different digital technologies applied to heavy load trucks. The results are from literature and consultations with experts. The potential energy-saving can be higher than 20% if more technologies are combined, although with diminishing marginal returns. The potential energy savings do not include indirect or consequential impacts (e.g. rebounds).

142 Digital Europe (2021) Digital action = Climate action: 8 ideas to accelerate the twin transition. Retrieved from https://www.digitaleurope.org/resources/digital-action-climate-action-8-ideas-to-accelerate-the-twin-transition.

143 D'Aprile, P. et al. (2020). Net-Zero Europe – Decarbonization pathways and socioeconomic implications.

144 Crow, D. & Millot, A. (2020). Working from home can save energy and reduce emissions. But how much? Retrieved September 8, 2022 from https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much.

145 We calculated the emission savings from avoided transport. It should be noted that working from home entails emissions from energy consumption at home, such as for electricity and heating. When taking those into account, the net CO2 emissions are still negative, meaning that working remotely has a smaller impact on the environment overall; see Crow, D. & Millot, A. (2020). Working from home can save energy and reduce emissions. But how much? Retrieved September 8, 2022 from https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much.

146 The CO2 emission savings from avoided car commute are calculated from the increase in days working from home post-Covid-19 pandemic compared to pre-Covid levels, for employed persons in the EU that can work from home and that commute by car. The sources for the calculations are: Eurostat (2022). Employment and activity – LFS adjusted series [LFSQ_ERGANEDM]; Eurostat (2022). Population on 1 January [TPS00001]; Eurostat (2022). Employed persons working from home as a percentage of the total employment, by sex, age and professional status [LFSA_EHOMP]; Eurostat (2022). Perception survey results [urb_percep]; Crow, D. & Millot, A. (2020). Working from home can save energy and reduce emissions. But how much? Retrieved September 8, 2022 from https://www.iea.org/commentaries/working-from-home-can-save-energy-and-reduce-emissions-but-how-much; ILO (2020). Working from home: Estimating the worldwide potential. Retrieved September 13, 2022 from https://www.ilo.org/global/topics/non-standard-employment/publications/WCMS_743447/lang--en/index.htm; The World Bank, urban population, retrieved September 3, 2022 from https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS; EEA (2022). National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved September 3, 2022 from https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-18.

147 Scott, M. (2022). Can business travel get into more sustainable flight-path post-Covid?. Retrieved September 8, 2022 from https://www.reuters.com/business/sustainable-business/can-business-travel-get-into-more-sustainable-flight-path-post-covid-2022-07-15/.

148 The emission savings from avoided air business travel are calculated from the share of global business travel post-Covid-19 pandemic compared to pre-Covid-19 levels. The sources for the calculations are: ICAO (2020). Annual report 2019 – The World of Air Transport 2019. Retrieved September 15, 2022 from https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.aspx; Graver, B. et al. (2020). CO2 emissions from commercial aviation: 3013, 2018 and 2019; Scott, M. (2022). Can business travel get into more sustainable flight-path post-Covid?. Retrieved September 14, 2022 from https://www.reuters.com/business/sustainable-business/can-business-travel-get-into-more-sustainable-flight-path-post-covid-2022-07-15/.

149 IEA (2021). Net zero by 2050 – A road map for the Global Energy Sector.

150 InterFlex (2020). Demand response & costumer empowerment. Retrieved September 8, 2022 from https://interflex-h2020.com/results-and-achievements/demand-response-customer-empowerment/.

151 InterFlex (2019). Demonstration report including KPI-Evaluation for all use cases. Version 1.0.

152 Merabet, G.H. et al. (2021). Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques. Renewable and Sustainable Energy Reviews, Volume 145. Retrieved September 8, 2022 from https://arxiv.org/ftp/arxiv/papers/2104/2104.02214.pdf.

153 B. Dong & K. Lam (2014). A real-time model predictive control for building heating and cooling systems based on the occupancy behavior pattern detection and local weather forecasting. Build. Simul. 7, 89–106.

154 Nest Labs (2015). Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results.

155 Nest Labs (2015). Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results.

156 Google Store. Nest Learning Thermostat. Retrieved September 8, 2022 from https://store.google.com/CA/product/nest_learning_thermostat_3rd_gen?hl=en-GB.

157 Calculated for large buildings and individual homes separately based on share of emissions affected, current and future adoption rates of technology and impact of technology where applied.

158 Cornago, E. (2021). The Potential of Behavioural Interventions for Optimising Energy Use at Home. Retrieved September 8, 2022 from https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home.

159 Reuven, S. & Chikumbo, M. (2016). Behavior Change Programs: Status report and Impact.

160 Behavior change programs: Status report and impact, Reuven Sussman and Maxine Chikumbo (2016), American Council for an Energy-Efficient Economy.

161 Degot, C. et al. (2021). Reduce Carbon and Costs with the Power of AI. Retrieved September 8, 2022 from https://www.bcg.com/publications/2021/ai-to-reduce-carbon-emissions.

162 Choudhry, H. et al. (2015). Greening the future: New technologies that could transform how industry uses energy.

163 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

164 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

165 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

166 Google Cloud, showcase. Explore the factory of the future. Retrieved September 8, 2022 from https://showcase.withgoogle.com/renault/main

167 Cornago, E. (2021). The Potential of Behavioural Interventions for Optimising Energy Use at Home. IEA. Retrieved September 8, 2022 from https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home.

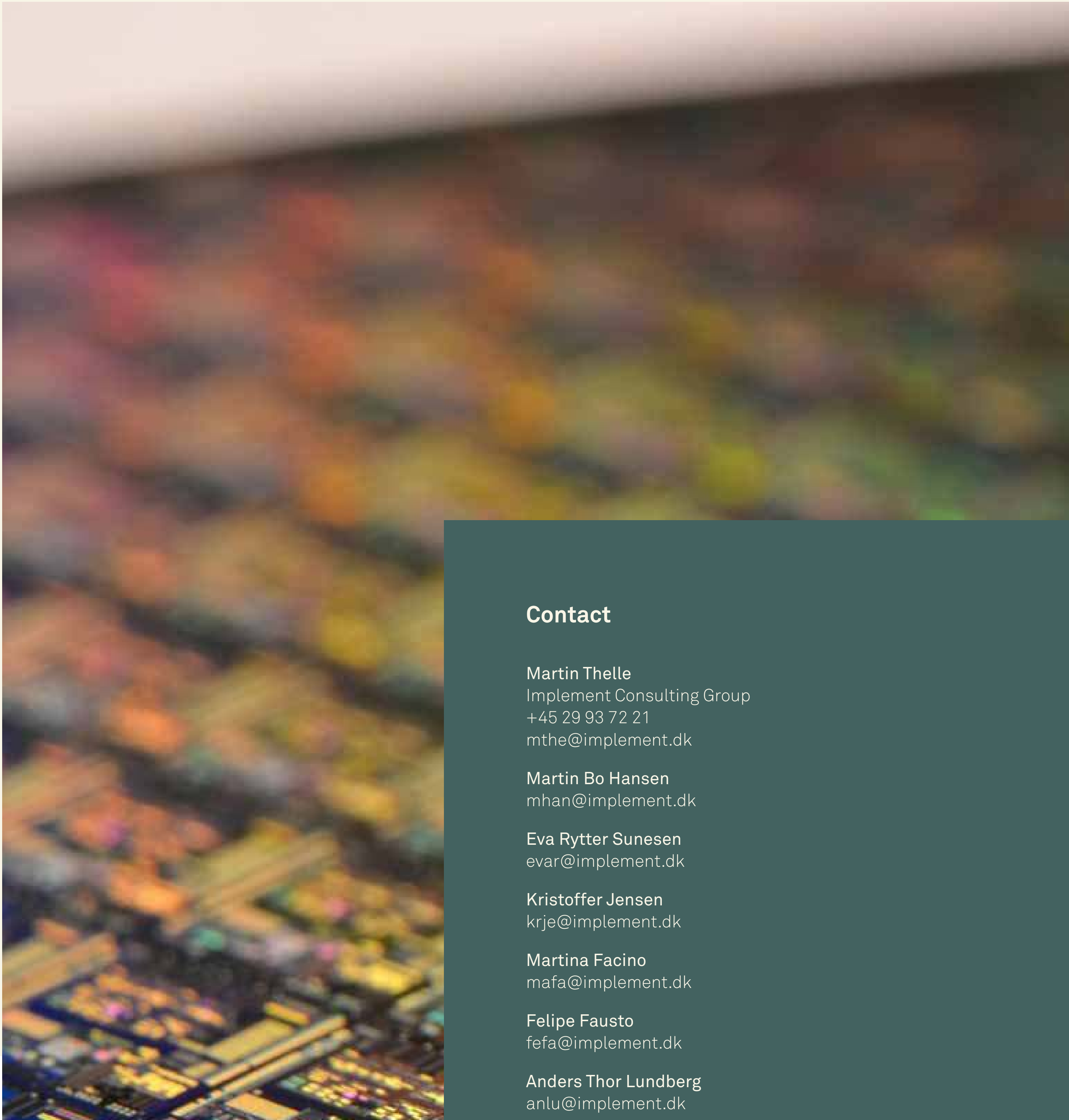
168 World Economic Forum (2021). Global Lighthouse Network: Unlocking Sustainability through Fourth Industrial Revolution Technologies.

169 Google Cloud, showcase. Explore the factory of the future. Retrieved September 8, 2022 from https://showcase.withgoogle.com/renault/main

167 Cornago, E. (2021). The Potential of Behavioural Interventions for Optimising Energy Use at Home. IEA. Retrieved September 8, 2022 from https://www.iea.org/articles/the-potential-of-behavioural-interventions-for-optimising-energy-use-at-home.

168 Supplychain (2020). How Demand-Driven Forecasting paid off for Nestle. Retrieved September 14, 2022 from https://supplychaindigital.com/logistics/how-demand-driven-forecasting-paid-nestle.

169 GFA & McKinsey & Company (2020). Fashion on climate – How the fashion industry can urgently act to reduce its greenhouse gas emissions.



Contact

Martin Thelle
Implement Consulting Group
+45 29 93 72 21
mthe@implement.dk

Martin Bo Hansen
mhan@implement.dk

Eva Rytter Sunesen
evar@implement.dk

Kristoffer Jensen
krje@implement.dk

Martina Facino
mafa@implement.dk

Felipe Fausto
fefa@implement.dk

Anders Thor Lundberg
anlu@implement.dk