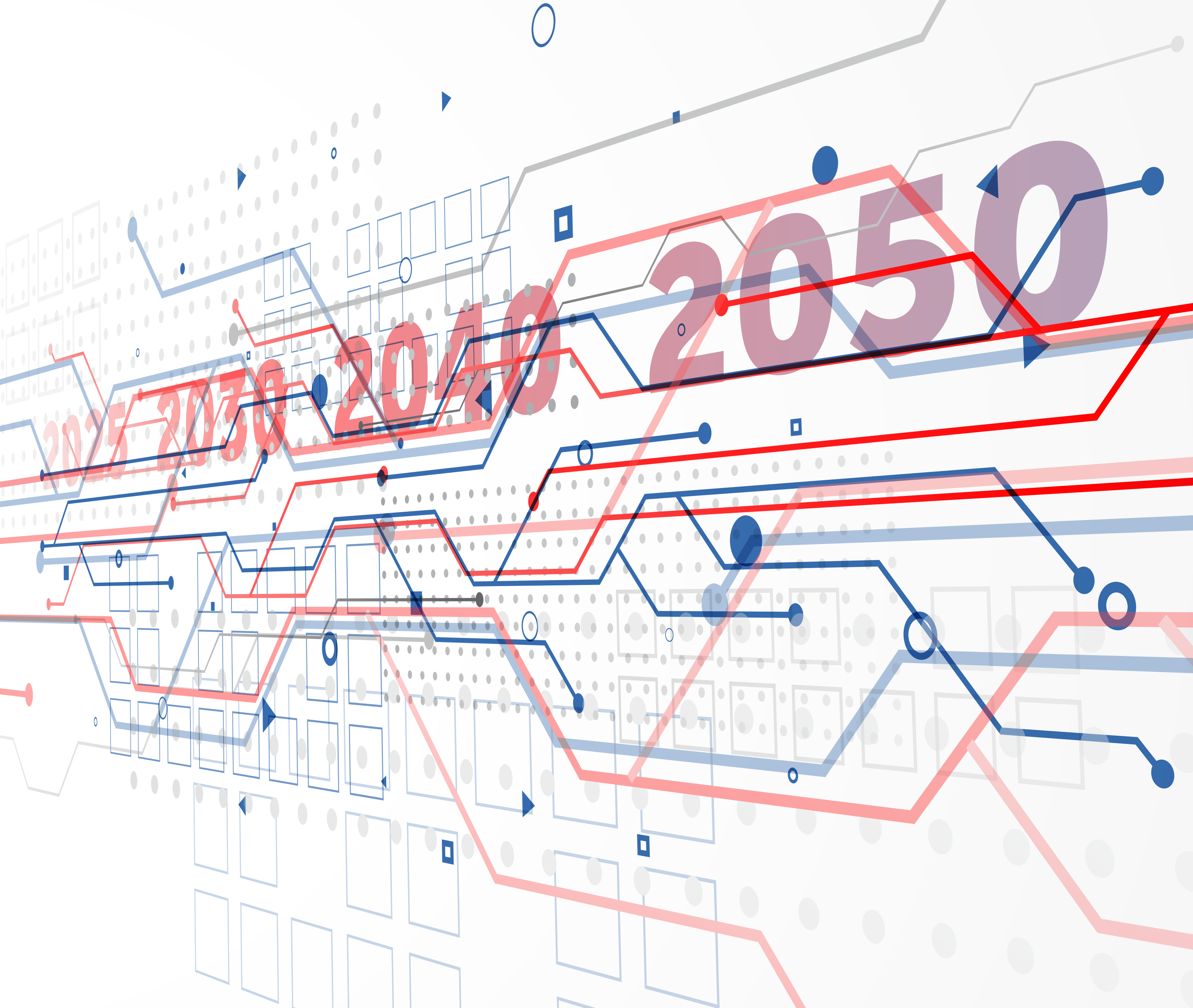

DIGITAL TRANSFORMATION FOR MORE SUSTAINABILITY

The Positive Impact of Digital Technologies and Infrastructure on the Carbon Footprint of Industry and Society

A study by

ARTHUR D LITTLE

DIGITAL INFRASTRUCTURES
WE ARE THE INTERNET

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ASSOCIATION OF THE INTERNET INDUSTRY

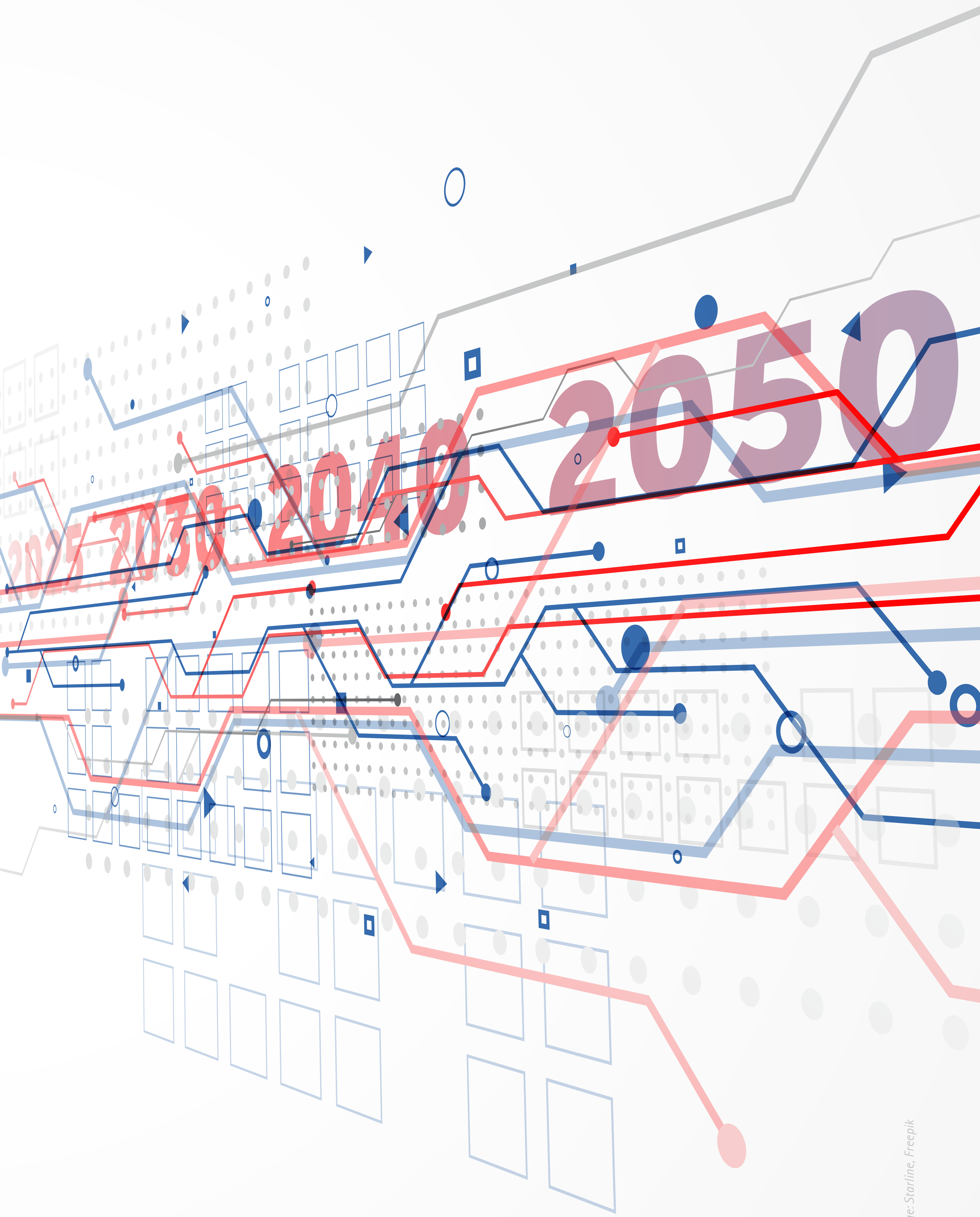


Image: Starline, Freepik

Content

Preface

Oliver Süme
Chair of the Board
eco Association

Dear Readers,

Sustainability is one of the most pressing issues of our time. In order to achieve climate goals, to use resources efficiently, and to reduce CO_2 emissions, the following factors are indispensable: digitalisation and the roll-out of digital infrastructures.

Already today, the eco-balance of digitalisation is proving to be positive; in numerous economic sectors, net CO_2 emissions are being saved on the strength of digital technologies and applications. To take just one example, we can simply look at the massive emissions savings gained during the Covid-19 pandemic based on the shift to hybrid work environments and digital collaboration tools: With the relocation to home office and consequent reduced commuting, vehicle emissions were reduced by 3.2 megatonnes in 2020 alone. The industry is also bearing its responsibility and driving the development of energy-efficient innovative solutions – be it in the form of intermodular mobility-as-a-service solutions, green IT and green coding or smart city concepts that make our cities more habitable, resource-friendly and energy-efficient. The same applies to the essential high-performance digital infrastructures 'behind the scenes': Germany's data centres are already among the most energy-efficient in the world. They form the foundation for a competitive and independent digital location in Europe based on an innovative data economy.

Digital infrastructures and digital technologies and services, however, also offer enormous potential for reducing greenhouse gas emissions – that is, if they are used consistently in the right domains. This study illustrates the enormous leverage effect that digital services and technologies can deploy as part of the solution in tackling the climate crisis. In this compact study, the authors have calculated the projected CO_2 emissions for Germany up to the year 2050. They have also modelled the expected emission savings based on digital levers in the Industry, City and Rural areas. To highlight just one of the key findings: By 2050, it is anticipated that emissions savings of 163 megatonnes of CO_2 will be achieved through the consistent use of digitalisation levers at these Industry, City and Rural levels. This equates to around 20 per cent of the total emissions forecast for Germany. If these are supplemented by innovative technologies in the field of data storage and transmission, CO_2 emissions could even be reduced by 30 per cent by 2050.

The results speak for themselves: Digital transformation is part of the solution. What is also clear: Germany and Europe will only be able to achieve their ambitious climate goals through the consistent use of digital technologies. This does not only concern direct elements of energy policy; a rapid roll-out of connected mobility and a strengthening of the technology location via innovative technologies such as AI or the Internet of Things (IoT) will also have a positive impact on sustainability and climate protection goals in the medium term.

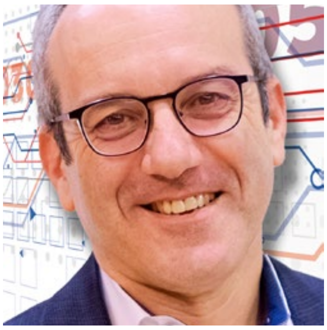
It is the responsibility of policymakers to now develop holistic and consistent concepts in close exchange with the industry in order to fully harness this potential: For a sustainable digital future.

I sincerely hope that the debate on the climate and sustainability effects of digitalisation will be conducted more intensively between politics, economy and civil society and, above all, that it will be raised to a fact-based level. For digital sovereignty, sustainable digitalisation and a leading role in the digital world market can only be achieved if European policymakers see sustainability and digitalisation not as opposing goals, but as two sides of the same coin – and if they promote and use the potential of the Internet industry accordingly. To achieve this, the eco Association will not only avail of the current study but will also initiate and provide further discussion formats and platforms for constructive exchange in the course of the year. I hereby cordially invite you to join us.

In this regard, I would therefore like to take this opportunity to draw your attention to our eco campaign **#JOINTHESOLUTION: We are part of the solution – the Internet industry**. Focal points here include technology-based solutions such as green IT or green coding, IoT and 5G-based smart farming solutions and connected mobility. By means of vivid practical examples and research results, you can witness the importance of digital transformation for a more habitable, resource-saving and sustainable future of our society, based on digital services and technologies.

We wish you an inspiring and insightful read!

Oliver Süme
Chair of the Board eco Association



Dr Béla Waldhauser, Spokesperson of the Alliance for the Strengthening of Digital Infrastructures in Germany

Digitalisation and sustainability – how politics and business create the perfect symbiosis

Thinking digitalisation and sustainability together from the very beginning - this is a core message of the **Alliance for the Strengthening of Digital Infrastructures in Germany**, which was founded in 2018 under the umbrella of the eco Association. After all, digital transformation and climate protection are not mutually exclusive, but rather complement each other, as numerous studies underline. In order to reach the EU's climate targets by 2030, the Internet industry is currently providing significant impetus: as the seedbed of digitalisation, data centres, in particular, offer innovative solutions. That said, the political framework conditions must also be favourable.

The positive effects of digitalisation are becoming increasingly clear, especially in times of crisis: digital technologies and applications provide valuable information flows within our society and keep the economy afloat. Most people have been aware of this since the beginning of the Covid-19 pandemic. At the same time, digitalisation is part of the solution to tackle the climate crisis: Even though digital applications and technologies consume electricity, the ecological balance of digitalisation is clearly positive. This study provides evidence for this thesis once again.

The Alliance for the Strengthening of Digital Infrastructures in Germany, founded in 2018 under the umbrella of the eco Association, aims to raise the awareness of politicians and the public to holistically use the potential of digitalisation for less CO_2 consumption. Because only then can Germany and Europe really achieve their climate goals.

Data centres are the foundation of the digital transformation. Accordingly, they also hold enormous potential for more sustainability. Through the consistent and strategic use of waste heat in the development of new districts, the city's heat supply, which has so far been based on gas as a primary energy source to the tune of 90 percent, could be realised in a climate-friendly way in the future. A strong data centre infrastructure thus offers an opportunity for future sustainable energy concepts, especially in conurbations.

So far, however, the waste heat from data centres has only been used at very few locations within the framework of pilot projects – and thus largely dissipates unused into the air. For many political and bureaucratic hurdles still exist that must first be overcome. These include the high electricity costs for the necessary heat pump operation.

Policymakers must promote the expansion of digital infrastructures

For a nationwide approach, the necessary political framework conditions are needed. This also requires a close exchange between politicians, the Internet industry, public authorities, municipal utilities and urban planners.

The use of artificial intelligence could make the use of waste heat from data centres even more attractive and profitable in the future. AI can also help to design planning phases effectively and to conceive and evaluate new concepts for data centre infrastructures.

With additional political support for the expansion of digital infrastructures, further investment in research into innovative technologies and a sustainability-oriented energy mix, it will also be possible to achieve a 100 per cent reduction in CO_2 emissions from data centres by 2030. This makes the industry a central building block for actually implementing the European Union's climate goals.

And the industry is already on the right track: European data centres are among the most energy-efficient in the world. Their energy consumption per computing unit has fallen tenfold over the past ten years. The CO_2 emissions of European data centres have already been declining for five years.

Data centre operators and the Internet industry as a whole are thus creating a suitable basis for further advancing climate goals. Political backing is now needed most for the perfect symbiosis between digitalisation and sustainability.

Dr Béla Waldhauser
Spokesperson of the Alliance for the Strengthening of Digital Infrastructures in Germany

Management summary

Background to the study/comments on the approach

This study examines the effects of digital transformation in the areas of Industrial, Urban (city) and Rural (rural living and farming) on resource efficiency and CO_2 emissions. The focus is on the application of innovative technologies based on digital infrastructure in the areas of data processing, data transmission and data storage. The study forecasts CO_2 emissions for Germany in 2050 and compares them with the potential savings from introducing digital technologies and services. The data on which the calculations are based come from official sources, e.g. EUR-Lex, the German Federal Environment Agency, the German Federal Motor Transport Authority, the German Federal Statistical Office and statistical databases (e.g. Statista), which have been supplemented by expert estimates. The effects were systematically calculated in a quantitative model.

One thing is clear: A better carbon footprint can be achieved through smart technologies in various sectors – particularly those based on Internet of Things (IoT) application scenarios. From smart meters that continuously monitor energy consumption to smart parking or waste management systems, there are countless ways to use technological innovations that have a huge positive impact on the carbon footprint. Smart technologies enable a more efficient use of energy and resources than analogue methods, for example, by helping to automate processes that increase productivity and reduce emissions.

Based on the calculations of the ADL Sustainability Model, the consistent use of digital levers can reduce annual emissions on the Industrial level by an average of 4.3 per cent, while 4.1 per cent is possible on the Urban level and 4.6 per cent on the Rural level.

Digital Levers For Industry

Smart Factory, Internet of Things (IoT) and digital twins: On the Industrial level, digital levers open considerable potential to reduce the volume of emissions through automation significantly, data exchange in manufacturing technologies and the use of artificial intelligence (AI).

- Internet of Things applications will reduce industrial CO_2 emissions by 37 percent by 2050. This corresponds to 55 megatonnes.

- Smart grids will have a positive impact on the CO_2 balance with a 9 percent reduction in emissions predicted by 2050. This is equivalent to 42.6 megatonnes.

Digital Levers For Urban Areas

Holistic smart city concepts and intermodular mobility-as-a-service concepts form the solution scenarios for increasing emissions in urban areas. Currently, for example, 95 percent of German transport emissions are attributable to traffic. Increasing urbanisation also poses an immense challenge: In Germany, urban housing is expected to increase by ten million housing units by 2050. Digital technologies and applications such as Big Data, Internet of Things (IoT), interoperability and artificial intelligence (AI) are some of the few levers to improve resource efficiency by enabling, for example, connected mobility, smart energy consumption and smart waste management.

- Smart city technologies could save 80,000 tonnes of CO_2 per day by 2030; by 2050, CO_2 emissions could be reduced by one-sixth of the total projected emissions.

- Connected mobility could reduce CO_2 emissions by 14 megatonnes by 2030. By 2050, smart mobility solutions could save 20 percent of the transport emissions forecast for the year 2050.

- Savings of up to 9.3 megatonnes of CO_2 are possible by 2050 through smart parking technologies.

- In the residential building sector alone, 60 megatonnes of CO_2 emissions are expected by 2050, which could be reduced by 15 percent using energy-efficient smart home technology.

- CO_2 emissions from waste management could be reduced by 95 percent by 2050. This corresponds to a CO_2 saving of 3.8 megatonnes.

Digital Levers For Rural Living + Farming

In particular, hybrid working models, digital collaboration tools and remote collaboration help to reduce commuting and associated emissions. This is particularly true in rural areas, where mobility options are scarce, and people from rural areas are dependent on their own cars, for example for their daily commute to work. Agriculture is also responsible for a large proportion of CO_2 emissions. Smart farming technologies, such as the use of sensors, can help. For example, they provide information about the condition of the soil and plants, enabling more efficient use of water, fertiliser and pesticides.

- The long-term shift to hybrid working models has the potential to save 25 percent of all emissions caused by commuting, reducing CO_2 emissions by 3 megatonnes by 2040.

- IoT deployment on farms can save 18 megatonnes of CO_2 by 2050. The use of digital innovations will reduce total agricultural emissions by 39 percent by 2050.

Overall Results Of All Digital Levers

- Digital levers in cities, rural areas and industry together enable CO_2 emission savings of 163 megatonnes by 2050. This corresponds to 20 percent of the total emissions projected for 2050.

- A savings potential of 104 megatonnes is forecast for the area of data storage and transmission.

- If the savings potentials through new technologies in the field of data storage and data transmission are added to the further digital levers on the Industrial, Urban and Rural levels, they will lead to a total reduction in CO_2 emissions of 30 percent by 2050.

Disclaimer/Footnotes

As sustainability is sometimes a fuzzy construct with different broad definitions, it should be noted here that sustainability in the context of this study is understood in the sense of reducing emissions, especially through digital technologies.

The emissions savings calculated for the future do not take into account any changes in the energy mix (e.g. switch to renewable energy such as green electricity), as changes in the energy mix - although expected - are not currently foreseeable and therefore cannot be predicted.

"As Europeans, we want to leave a healthier planet behind for those that follow. We obviously cannot turn a blind eye to the climate challenge; we must look to the future."

Jean-Claude Juncker, State of Union address

93 %

of Europeans believe climate change to be caused by human activity.

Short introduction

Germany is facing a multitude of challenges in evaluating climate neutrality. Besides sustainable energy production and socio-economic aspects, the impact of advancing digital transformation is increasingly under scrutiny. However, the authors of this impulse paper argue that a high-performance data economy and, specifically, the related digital infrastructure will be the key solutions to the climate crisis. The required digital infrastructure and its potential to reduce emissions is a particular focus. This view is echoed by Andreas Kuhlmann, CEO of the German Energy Agency (DENA): "Energy efficiency, renewable energies and data are the three most important pillars in achieving climate neutrality".

Core content

Global sustainability targets require innovation across all technologies, including digitalisation

Climate change has become an increasingly critical concern over the past decades, requiring progressive measures to remediate its negative impacts. The gravity of this issue is reflected, inter alia, in the United Nations 2050 Agenda for Sustainable Development, which calls for economy-wide green transitions. As a result, the Paris Agreement has set a framework to limit global warming to 1.5°C and achieve worldwide climate neutrality by 2050. Whilst increased globalisation has allowed for the exponential progression of society, its repercussions on our environment are unfavourable for our future, with the past decade (2010-2020) being the warmest on record. Our current traditional way of living, driven by increased resource and energy consumption, is not sustainable in the long term. It should be noted that, despite some forms of technology contributing to the growth of CO_2 emissions over recent decades, the vast majority of digital technology yields a considerably larger role in reducing CO_2 emissions in application areas such as industrial manufacturing, logistics, mobility and more and hence play a vital role in driving innovation in sustainability.

The European Union has outlined goals to reach net zero emissions by 2050. However, practical implementation is left up to the Member States. This decision will mostly likely result in starkly deviating framework conditions for the relevant economic players due to the different energy mix compositions of the Member States.

Sustainability is a crucial consideration for the future due to the expectation for the absolute volumes of energy consumption to continue to increase over time and the full changeover to renewable energies is still taking time. In this report, we define sustainability as the reduction of greenhouse gases such as CO_2 and equivalents across different (also digital) technologies.

This aforementioned growth of energy consumption is, among other things, driven by the increasing electrification of our everyday life as well as the emergence of electronic goods such as electric

Fig. 1

Extract from the European Commission Climate Neutral Plan by 2050

Strategic priorities: Road to climate neutral economy

#EU2050
References to digitalisation

Fully decarbonising Europe's energy supply: Large scale electrification of the energy system coupled with deployment of renewables will decarbonise the energy supply

Embracing clean, safe and connected mobility: Decarbonising the transport sector by using alternative means of transport, connected and automated driving combined with the roll-out of electric vehicles & use of alternative fuels

Putting industrial modernisation at the centre of a fully circular economy: Modernising existing installations and investing in new carbon neutral and circular economy compatible technologies and systems

Maximising benefits from energy efficiency: Reducing energy consumption by close to half between 2005 and 2050

Developing smart network infrastructure and interconnections: A modern and smart infrastructure, ensuring optimal sector coupling and enhancing regional cooperation

Reaping the full benefits of bioeconomy and creating essential carbon sinks: Creating natural sinks by developing more sustainable land-use and agriculture

Tackling remaining CO_2 emissions with carbon capture and storage: Compensating for remaining greenhouse gas emissions in our economy and creating negative emissions

vehicles, with around 7 million sold globally in 2021 and 9 million forecasted to be sold in 2022. But also smartphones have seen growth in market penetration globally increasing by almost 10 % annually since 2016. The share of households in Germany owning at least one computer reached new highs with 90 % in 2020. On top of the increased energy use, these developments contribute to ever-increasing data traffic within a complex digital world which, in turn, consumes energy.

Exponential technological advancement has been driven by previous industrial revolutions globally; however, this advancement is predicated on significant energy generation and consumption. Since energy is still produced primarily from fossil sources, this development yields significant costs to our environment. Hence, in order to achieve the set climate goals and, therefore, a sustainable way of life, the issue of energy efficiency will be of even larger importance.

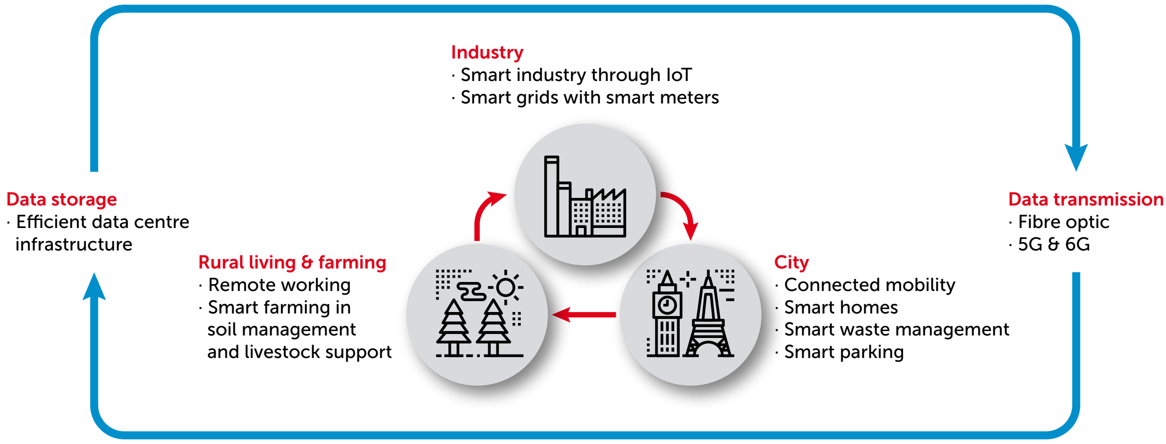
The energy historian Vaclav Smil noted that, "Historical evidence shows unequivocally that secular advances in energy efficiency have not led to any declines of aggregate energy consumption". As of 2021, the ICT sector contributes significantly to the overall electricity consumption; some scenarios stating up to 4 % (global) (Malmodin and Lunden, 2018), others roughly 2.5 % (Europe) (Hintemann and Hinterholzer, 2020). However, the sector only produces 1.4 % of all carbon emissions compared to the transport industry producing 27 % of all emissions, demonstrating that energy consumption cannot be equated with CO_2 emissions.

Data centres, as part of the ICT sector, are not direct CO_2 emitters. However, the manufacture of, e.g., server racks and construction still emits CO_2, resulting in a calculated emission value. The respective energy mix of the specific site can worsen or improve this calculation in comparison to the median. Similarly, electronics such as mobile phones or laptops also do not directly create emissions, but rather their manufacture and daily use. With the digital transformation of the economy and society, larger data volumes require an ever-greater amount of processing power and storage capacity, with a further increase in energy demand.

When considering achieving a climate-neutral and sustainable digitalised landscape, two key challenges are thus prevalent. Firstly, whilst transforming to 100% green energy, production levels must remain on par with ever-increasing energy demands. The current speed of transformation is undoubtedly too slow. This reliance on ever more volatile energy sources and the lack of an energy power management system contributed to Germany experiencing its first increase in power supply cuts in late 2021 and 2022 since 2017.

Secondly, the impact of the Russian war of aggression against Ukraine has shown a shortage of natural gas supply and triggered a surge in energy prices. This is exemplified by the re-firing of coal plants, representing 45 GW capacity. The question of sustainability then evolves to how politics, the economy and society tackle these challenges without lowering their quality of life. One answer is: With the help of digitalisation.

Fig. 2 **Overview of digitalisation levels**



Digitalisation remains the central tool for reducing CO_2 emissions without a significant compromise in living standards

The clear strengths of digitalisation are highlighted by its pivotal role in reducing emissions and sustaining living standards. With this impact evidenced during the pandemic, as users of Microsoft Teams doubled to 145 million, Zoom participants increased 30-fold to 300 million, and a significant amount of CO_2 was saved through the collapse of commuter traffic (Statista, 2023).

Fundamentally, we see the impact of digitalisation on three distinct levels; Industry (manufacturing), City (urban habitats), and Rural (non-urban habitats and farming) – See figure 2 above. Each level encompasses digital levers to enable a more efficient use of resources whilst maintaining the expected progression of living standards.

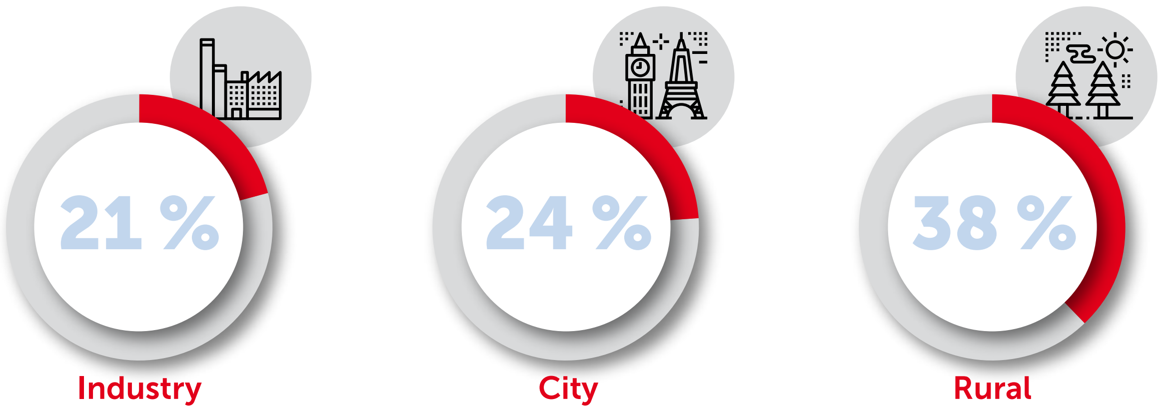
Digital levers are digital technologies that further drive the sustainability potentials of existing processes (see figure 3):

- Industry levers focus on smart grids and smart industry;
- City levers (smart city) target the alleviation of emissions through connected mobility, smart homes, waste management and connected parking;
- Rural levers take remote work and intelligent agriculture (smart farming) into account.

Besides these three fundamental lever groups, we see two underlying levels supporting digitalisation efforts; data storage and processing as well as data transmission. These will be discussed further down.

Fig. 3

Overview of CO_2 impact by selected digitalisation levers in each level: % of emissions saved in 2050 thanks to digitalisation, from baseline of projected gross German emissions in 2050



ADL Sustainability Model

For the assessment of emissions and savings for the three lever groups and the two support levels (data storage and data transmission), a model was created in which historical emission data for the individual categories, such as commuter traffic or power grids, were forecasted until 2050. The emission prediction is based on the underlying drivers of the individual categories (such as ride sharing apps and optimisation of routing for commuter traffic) and corresponding growth rate estimations. The emission development after the implementation of innovations enabled by digitalisation, such as groupware or IoT, was also modelled. The data was taken from official sources such as EUR-Lex, the German Environment Agency, the German Federal Motor Transport Authority (KBA), the Federal Statistical Office of Germany and statistic websites (e.g. Statista) and complemented by expert estimations.

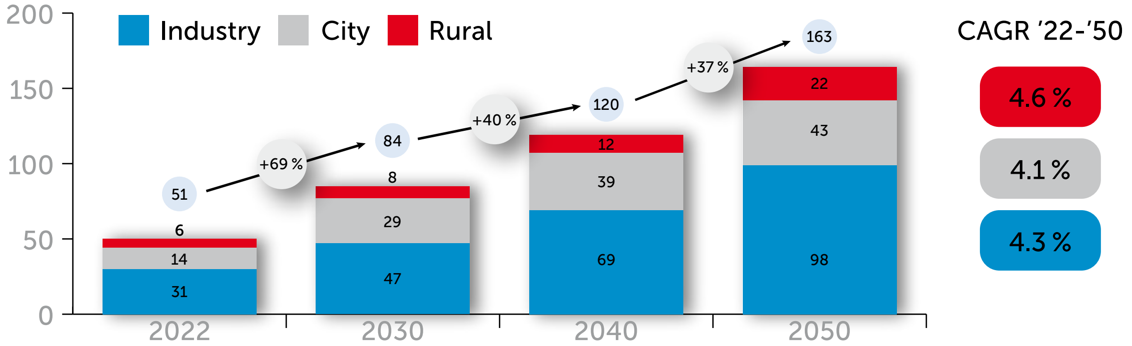
Careful attention must be paid to all three levels (Industry, City, and Rural), with historical trends projecting combined CO_2 emissions of up to 870 megatonnes (Mt) by 2050 for these levels in Germany. This excludes the impact of the energy production shift, as it is currently difficult to predict (see the shift to liquid gas and coal-fired power stations after Russia started the war in Ukraine). However, Germany's commitment to the Paris Agreement dictates emission reduction to 60 Mt. Ultimately, digitalisation provides the key tool to facilitate these necessary reductions and to enable Germany to realise its global promise to cut 12 % of emissions projected for 2030 (see the ADL Sustainability Model) to 84 Mt (see figure 4). Digital transformation, therefore, plays a big part in Germany upholding its climate promise.

Fig. 4

Overview of CO_2 emissions saved due to digitalisation across the Industry, City, and Rural levels between 2022-2050 in Germany, based on the ADL Sustainability Model.

CO_2 emissions saved
Germany, 2022-2050, saved in indicated year, in megatonnes (Mt)

Source: Arthur D. Little Sustainability in Digitalisation Model



Industry

Digital levers in the industry setting hold significant potential to reduce emissions markedly through the use of automation, data exchange in electricity/manufacturing technologies, and the application of AI (artificial intelligence). This is visible in both the supply and output sides of industry manufacturing. Furthermore, industry trends exemplify that digital technology will be the main source of future economic and environmental prosperity, thereby providing an incentive to further optimise these technologies.

Smart industry

Similar benefits of smart industry advancement can be seen in energy consumption reduction through IoT (Internet of Things), augmented reality, enterprise systems, and digital twins. Digital twins, for instance, create a digital simulation of a physical product allowing for simultaneous digital modification and customisation – with this minimising energy costs from physical resources. Adoption of such progressive technologies is expected to grow three-fold over the next decade – highlighting their strong future role in emission reduction. At present, such innovations are generally used by larger enterprises, but as mid-market accessibility increases, the number of companies tackling their carbon footprint is set to grow. In 2021, 150M IoT devices were used across the German industry, with this expected to reach 380 M by 2030. IoT devices have a considerable impact on industrial CO_2 emissions – enabling a 37 % (55 MT) reduction by 2050 (see figure 5).

Smart grids

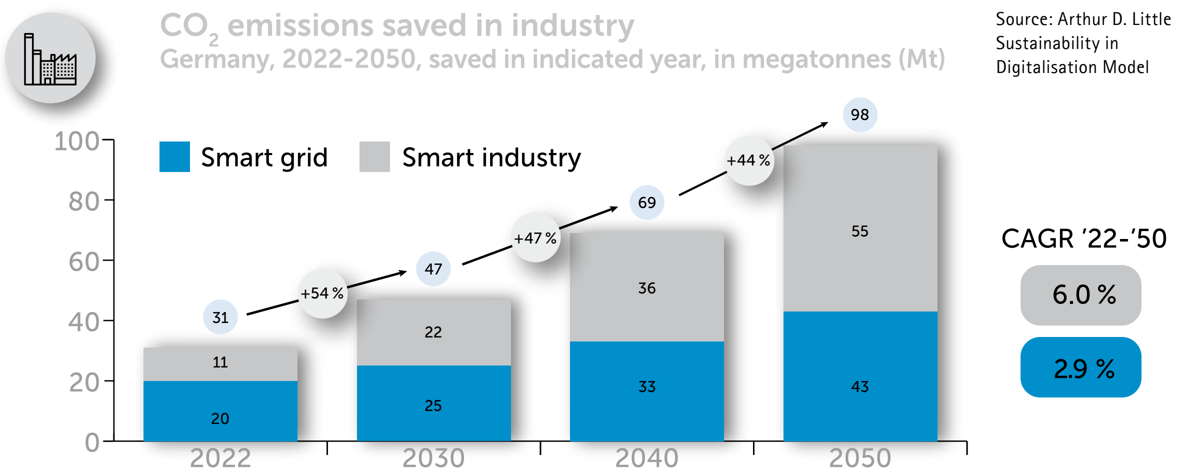
Smart grids facilitate the efficient supply of energy resources through innovations by enabling the energy transition towards a decentralised power grid fed by renewable energies. One such contributing innovation is, for example, smart meters, which enable two-way communication between utilities and customers by incorporating demand-response technology and big-data analytics. The demand for smart meters is expected to grow by 30 % in the next decade, reaching 15M units in Germany by 2030. This growth is driven by their enablement of self-monitoring and lowering electricity costs. As a result, we estimate that by 2030 this technology will reduce CO_2 emissions by 9 % and save 42.6 Mt by 2050 (see figure 5).

City

From an ecological perspective, the increase in urban housing is expected to be a large contributor to carbon footprint expansion – with a further 10 M German homes by 2050. Smart cities offer a possible solution to the increased emissions in cities through the combined use of big data, IoT, interoperability of digital devices, and AI. Digital technologies and use cases improve the efficiency of resource usage whilst developing urban lifestyle through connected mobility, smart energy use and waste management. Without sustainable and digital action, CO_2 emissions from smart cities will reach 300 Mt in Germany by 2050, compared to 1600Mt in Europe. However, the components of an integrated smart city concept will enable savings of over 80,000 CO_2 tonnes per day in Germany by 2030 – cutting a sixth of projected emissions by 2050.

Fig. 5

Overview of CO_2 emissions saved thanks to digitalisation in Industry between 2022-2050 in Germany



Connected mobility

The global digitalisation of mobility offerings is creating interdependencies between constant connectivity and functionality, with this expected to prompt a surge in the use of smart and connected cars. While the number of smart/ connected vehicles in Germany is expected to reach almost 20 million by 2022, with full market penetration projected by 2034, adoption in Europe is somewhat slower, with 93 % penetration by 2035. The expected widespread use of smart cars is driven by consumer preferences for increased accessibility to smart services, such as advanced driver-assistance systems (ADAS) which find efficient traffic routes and minimise the chances of a collision. The adoption of such technology is crucial for sustainability in the mobility sector, as the lack of flexible urban mobility is a significant current contributor to total CO_2 emissions – with 95 % of German transport emissions arising from traffic (German Federal Ministry for the Environment, Nature Conversation, Nuclear Safety and Consumer Protection, 2022). Further to this, consideration must be given to the significant potential of connected personal and public mobility networks for Germany's sustainability targets. Based on this highlighted digital lever, CO_2 emissions can be cut by 14 Mt in 2030 – with this representing almost 20 % of transport emissions by 2050 (see figure 6). In comparison to other EU states, Germany has an above-average savings potential, being responsible for 36 % of the EU-wide reductions of 42 Mt in total.

Smart parking

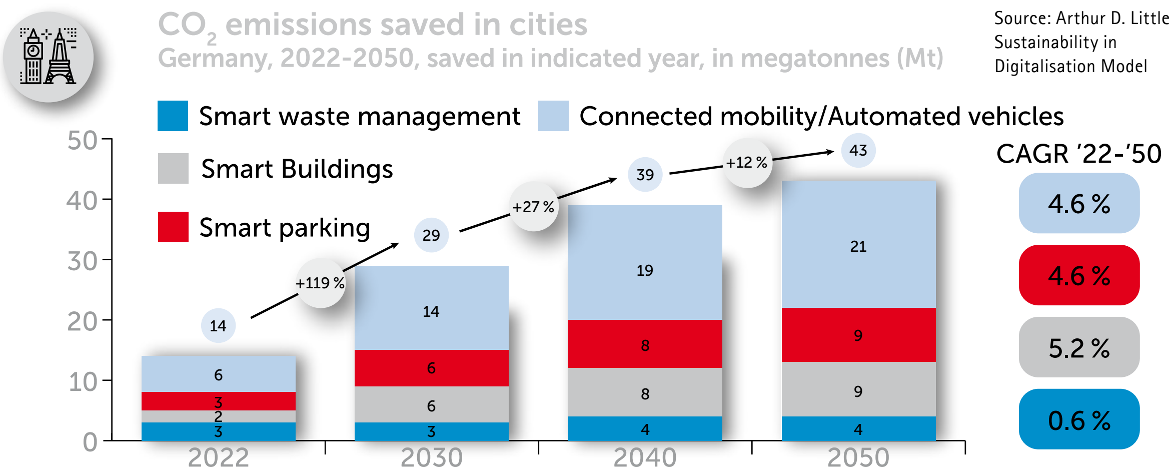
The efficiency-improving role of smart cars is also evident when it comes to parking, with their incorporation of real-time sensors eliminating unnecessary fuel consumption when looking for a parking spot and thus making the search more sustainable. Analysis highlights that even such a simple application of this technology can allow for up to 9.3 Mt of CO_2 to be saved by 2050 (see figure 6).

Smart homes

An additional, often overlooked concern is the emissions from housing, with German homes emitting 85 Mt of CO_2 (accounting for 23% of city-related emissions and matching the EU average) in 2021. Smart homes tackle this issue with energy efficiency, incorporating the usage of prediction technologies based on the environment. Whilst considerable quantities of this sector's emissions have already exhibited decreasing trends, due to advances in building resources, further action is still required. Without digitalisation, 60 Mt of CO_2 emissions are expected from this sector alone in 2050. However, 15% of these emissions can be curbed through increased adoption of smart home technology. 20.5 M households and office buildings will adopt automated heating by 2026, whilst 26.7 M will adopt smart lighting/security actuators, and both smart security and smart appliances will see 16 M adoptees, with this accumulating to a potential saving of 8.5 Mt of CO_2 emissions in 2050 (see figure 6).

Fig. 6

Overview of CO_2 emissions saved thanks to digitalisation in cities between 2022-2050 in Germany



Smart waste management

Smart technology also holds great potential in achieving net-zero emissions within waste management. Germany not only leads the EU recycling ranks, but also has the largest installed capacity of municipal waste energy. However, absolute volumes of waste are increasing by 3 million tons per year and will reach 500 million tons by 2050, accounting for 4 Mt of CO_2 emissions in 2050. 95 % of these emissions (corresponding to 3.8 Mt), can be alleviated by 2050 through smart management methods such as composting plants, smart sorting and fill-level sensors to optimise collection routes. There is a direct link between digitalisation and the benefits of smart waste management (see figure 6).

Rural living and farming

Remote Working

Lastly, the rural environment is another competitive landscape where digitalisation will play a key role in reducing CO_2 emissions. The COVID-19 pandemic facilitated a shift in the relocation of work from the office to the home office. This transition would not have been possible without developing and refining digitalised hardware and software, and collaboration tools. This shift alone eliminated a considerable portion of the pre-pandemic commute to work – with an almost 25 % increase in German employees working from home or in a hybrid environment – and thus a consequent 25% reduction in total kilometres driven in Germany over 2020. As a result, this trend reduced vehicle emissions by 3.2 Mt in 2020, with this further reflected worldwide by a 15 % reduction in global oil consumption. Societal preferences have pushed for long-term adoption of the hybrid approach, with the potential to alleviate a quarter of overall emissions from work-related commuting, saving 3 Mt of CO_2 emissions yearly by 2030 (see figure 7).

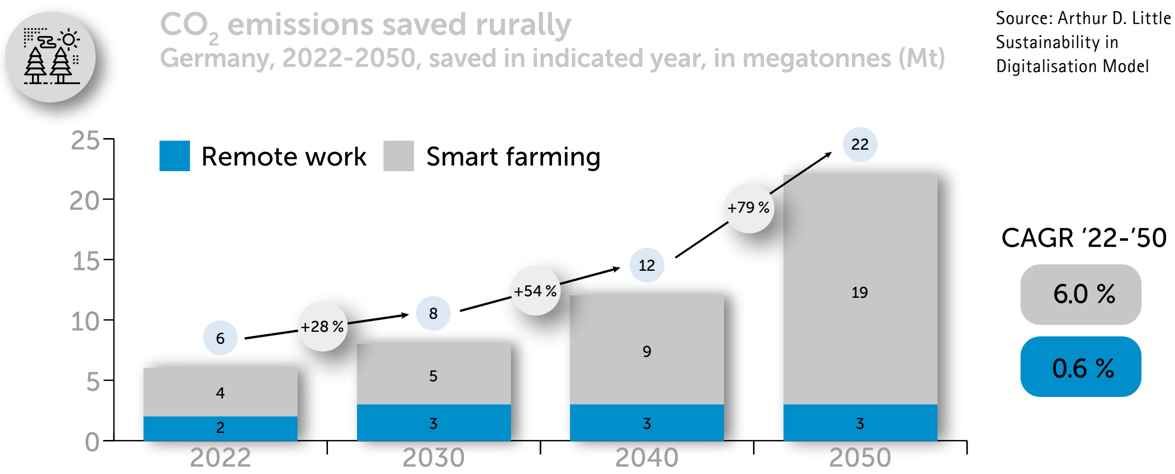
Smart Farming

Digitalisation also enables efficiency gains within the farming sector – driving a new era of development with technologies such as IoT, drones and advanced data analytics. Agriculture is expected to experience major progression through IoT technology – such as automated soil management – with a significant impact on emission reduction. The number of IoT devices in German agriculture is expected to double over the next decade and increase tenfold (to 2 million) by 2050 – with this enabling 19 Mt of CO_2 emissions to be saved by 2050. Whilst the number of cattle in Germany is decreasing by 100,000 each year, from 11M in 2021 to less than 8M projected in 2050, emissions from their farming are still a major concern. Digitalisation will play a key role in reducing this carbon footprint – with new technologies relying on smart monitoring for illnesses and methane production saving 2 Mt of CO_2 emissions yearly. Combined, the application of these emerging technologies are likely to alleviate 39% of total farming emissions by 2050 (see figure 7).

Across Industry, City and Rural sectors, digitalisation will play a significant role in enabling Germany to reach its goal of a sustainable future whilst maintaining its population's quality of life. Combined, the aforementioned levers will enable savings of 163 Mt of CO_2 emission by 2050, accounting for almost 20 % of Germany's total projected emissions.

Fig. 7

Overview of CO_2 emissions saved thanks to digitalisation in rural living and farming between 2022-2050 in Germany



Data centres are energy consumers, yet enable sustainable digitalisation

Since the turn of the century, an increasingly important practice within digitalisation is cloud computing – with this term referring to the usage of remote online servers to store and process data. The cloud computing industry and associated data storage have increased exponentially – approximately tenfold over the past 5-10 years – with a 20% increase in spending on cloud services per year with an associated growth in data traffic. To support such a flow of information in an expanding digital society, data centres are required as the backbone of digitalisation – with physical data centres being the key infrastructure component to enable this process and house all cloud applications.

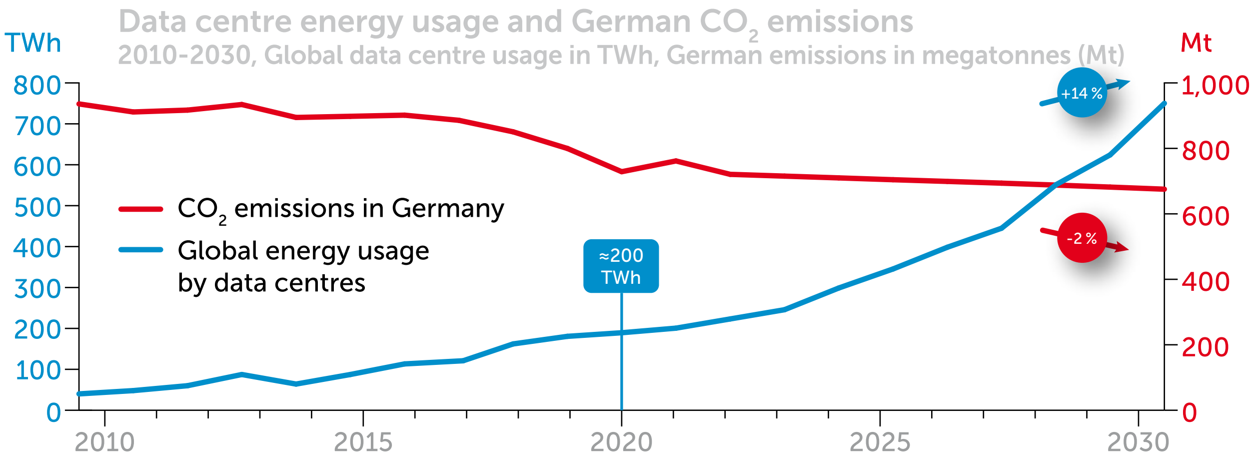
Consequently, the global data centre market is expanding, with increased spending on data centre construction forecasted – from $51 billion in 2021 to an estimated $71 billion in 2027. Due to the nature of these centres and the continuous increase in the size of these facilities, their associated energy consumption has increased from 97.6 TWh in 2015 to approximately 200 TWh in 2020 (iea, 2022) – with the EU's share at 104 TWh in 2020 (Garcia, 2022), according to one possible scenario for this development. As a result, data centres account for 1% of global electrical consumption (iea, 2022) and approximately 1% of global CO_2 emissions (Datacentre Frontier, 2021). In light of the potential sustainable use cases (see impact on the fields of application), a rather small share compared to other economy and industry sectors.

In Frankfurt am Main, energy suppliers and data centre operators already implement green initiatives to recycle the excess heat generated from around 60 data centres. Whilst the excess heat was previously released into the atmosphere, a pilot project, for example, is successfully transferring some of it to the Eurotheum skyscraper providing heating and hot water facilities, saving significant energy resources.

A new residential quarter, "franky", is currently being built in Frankfurt's Gallus district. Within the new quarter, over 1,300 residential units are being built to KfW 55 standard on six construction sites; 380 of which are publicly subsidised. The plans also include three day-care centres, six children's playgrounds as well as commercial and retail space. About 80% of the total heat demand will be covered by the waste heat generated in the server farms of the neighbouring Telehouse data centre. This is a unique process in Germany on this scale and will save around 440 tonnes of CO_2 per year compared to conventional heat generation.

Fig. 8

Global data centre energy usage and German CO_2 emissions between 2010-2030 (iea, 2022; German Environment Agency, 2022)



Germany's data centres currently produce enough waste heat to heat around 350,000 homes. That is roughly equivalent to the number of apartments in the city of Bremen. The German Federal Ministry for Economic Affairs and Climate Action under Robert Habeck now wants to oblige operators to use this waste heat more effectively. In its Energy Efficiency Act, the German federal government initially provides for a levy of 10% of waste heat for data centres that begin operation on or after 1 July 2026. In the following two years, the levy is to be increased in stages to 15 % or 20 %.

Germany can further follow the examples in the Nordics, where next-generation district heating networks are common (e.g., Fortum in Helsinki, Finland). Therefore, it is evident that such efficient resource usage holds significant potential to maximise emission efficiency from data centre operations.

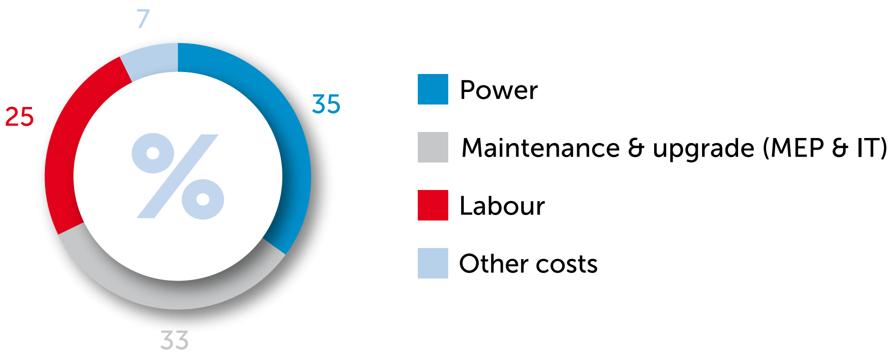
The biggest expense for data centres is energy supply representing around 35% of costs, making the sourcing of sustainable energy an economic interest and an environmental one for the operators themselves. Beyond that, the procurement of green energy has gained importance in recent years. Large players in the segment are investing €1 billion in the construction and expansion of cloud data facilities and sourcing renewable energy in Germany. Others have already implemented green methods, such as sourcing all electricity from hydropower plants.

Further new technologies to optimise the sustainability and efficiency of data centres include new forms of cooling. Liquid and immersion cooling allow for more efficient cooling systems in turn leading to efficient energy usage ranging up to 15 % per server. However, these technologies are not yet widely available and implemented to provide a concurrent solution to the energy question. Significant large players are planning to invest more than €700 million into making future-proof technology such as immersion cooling scalable in their data centres. Besides this, building equipment and processes are being developed to ensure the construction of data centres are as carbon-neutral as possible. Examples include bricks made of algae as sustainable building material and modular construction to ensure efficiency gains in the set-up of data centres.

Sustainability is an important topic that is also gaining greater attention in the IT industry. Data centres are a significant part of the IT infrastructure and consume a considerable amount of energy due to their high power consumption and cooling requirements.

Although overall data volume has surged greatly in the past, data centres were able to achieve significant efficiency gains, as, for example, energy consumption per workload has been reduced by a factor of six since 2010, and the energy efficiency per transmitted GB by the factor of 12 (Hintemann and Hinterholzer, 2020). It is clear that the data centre industry is only at the start of its "green energy transition" and energy optimisation. There are still a lot of elements on which they can improve.

Fig. 9 **Data centre cost split**



Digital infrastructure is becoming significantly more efficient over time

Whilst the three aforementioned levels and their levers are pathways for the alleviation of CO_2 emissions in their individual arenas, the underlying driver to the success of this digital movement lies in energy-efficient data transmission and storage. Infrastructure improvements such as nationwide fibre roll-out and construction of 5G networks driven by many players such as Deutsche Telekom or Vodafone lead to increased sustainability gains.

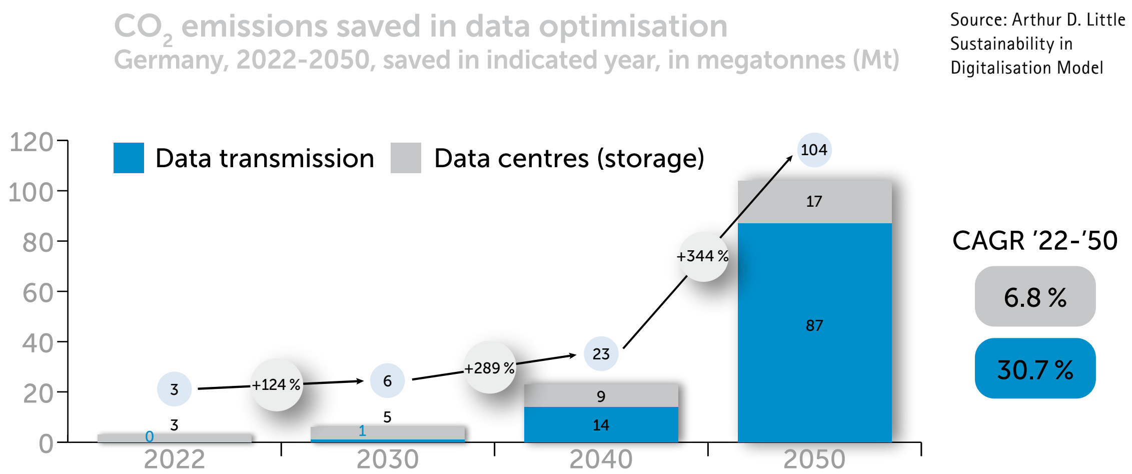
As mentioned above, data centres are the backbone of the digital transformation. Despite already large demand energy of the German data centre industry, even set to triple between 2023 by 2050 (see the ADL Sustainability model), data centre power usage efficiency (PUE) is increasing, significantly reducing subsequent CO_2 emissions. Every incremental improvement of 0.1 PUE represents around 105,000 tonnes of CO_2 saved per tWh in 2035. The historical PUE currently stands at 1.63 PUE for existing data centres, with latest reports expecting a decrease to 1.3 for newly-built data centres from 2025 onwards. This trend is set to expand through innovative technologies such as immersion cooling and sustainable infrastructure construction. By 2050, data centres are expected to be increasingly sustainable, bringing the PUE close to 1.0 and saving 17 Mt of CO_2 emissions, accounting for 60 % of emissions generated by these facilities (see figure 10).

Alongside the storage data, data transmission is seeing gains in energy efficiency. Data transmission is the transferring of any digital content from devices to their specified destination/s through wired or wireless communication mediums.

Volumes of data are growing exponentially, with 62 XB transferred across Germany in 2021 and projections reaching 30,000 XB in 2050. These projections correspond to 110 Mt of CO_2 emissions, which is 13 % of the total in Germany, though this is only if the energy mix in Germany remains unchanged and without offsetting the CO_2 emissions saved in real terms. However, data transmission is becoming increasingly efficient over time, primarily through two methods. First, the transitioning of data transmission from copper wire to fibre optic enables significant energy savings. Fibre also allows for increased resilience which results in a lower upkeep need. Deploying fibre is projected to save 270,000 tonnes of CO_2 emissions by 2026. Secondly, the transition from 4G to 5G and future transitions to 6G will drive improvements in sustainability and energy efficiency for mobile data transmission. CO_2 emissions can be reduced by up to 60 % in 2030, corresponding to 1.2 Mt of CO_2 emissions (see figure 10). With 6G expecting to reduce 80 % of emissions, the savings will reach 14 Mt in 2040, and roughly 90 Mt of CO_2 emissions in 2050 (see figure 10).

Fig. 10

Overview of CO_2 emissions saved thanks to data storage and data transmission between 2022-2050 in Germany



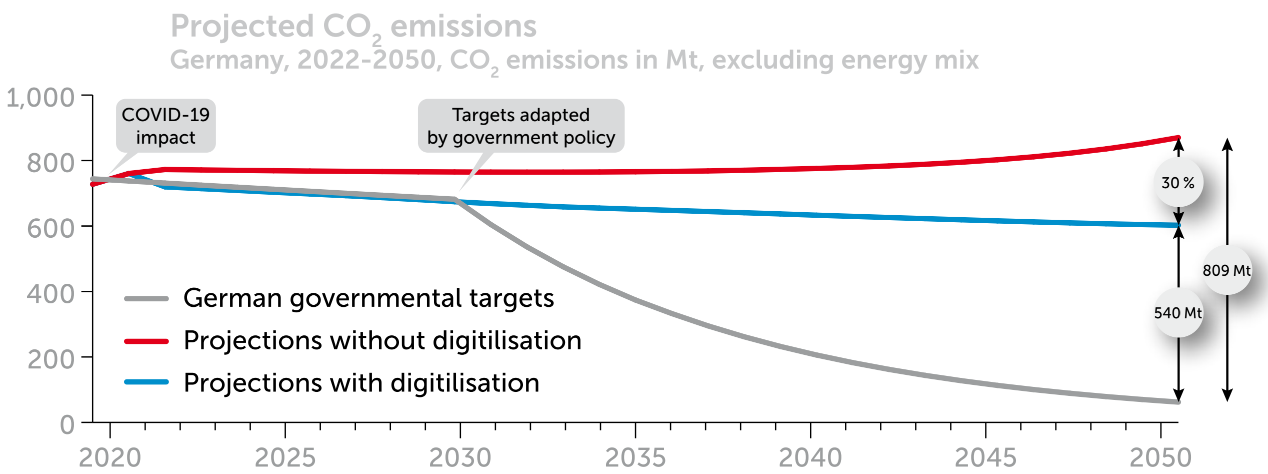
Digitalisation allows significant savings in projected German emissions

As mentioned above, the CO_2 emissions saved across Industry, City, and Rural sectors thanks to digitalisation will enable savings of 163 Mt of CO_2 emissions by 2050, accounting for almost 20 % of Germany's total projected emissions. Adding the 104 Mt CO_2 emissions saved in 2050 by data transmission and data storage, digitalisation alone can have up to 30% impact without compromising Germany's quality of life (see figure 11). The achieved savings still fall up to 540 Mt short of the German governmental overall targets proposed by 2050, so the government must implement real CO_2 savings in other industry sectors and traffic as well as advance the energy transformation towards renewable sources.

The digitalisation figures shown do not take any change in the energy mix into account [more details in the following chapter]. The CO_2 emissions saved will be multiplied as Germany moves towards fully sustainable energy generation, allowing this gap to be closed in the long term. While digitalisation alone will not change Germany's carbon footprint, it is a critical element in an integrated strategy across all levers and behaviours.

Fig. 11

Overview of projected CO_2 emissions by 2050

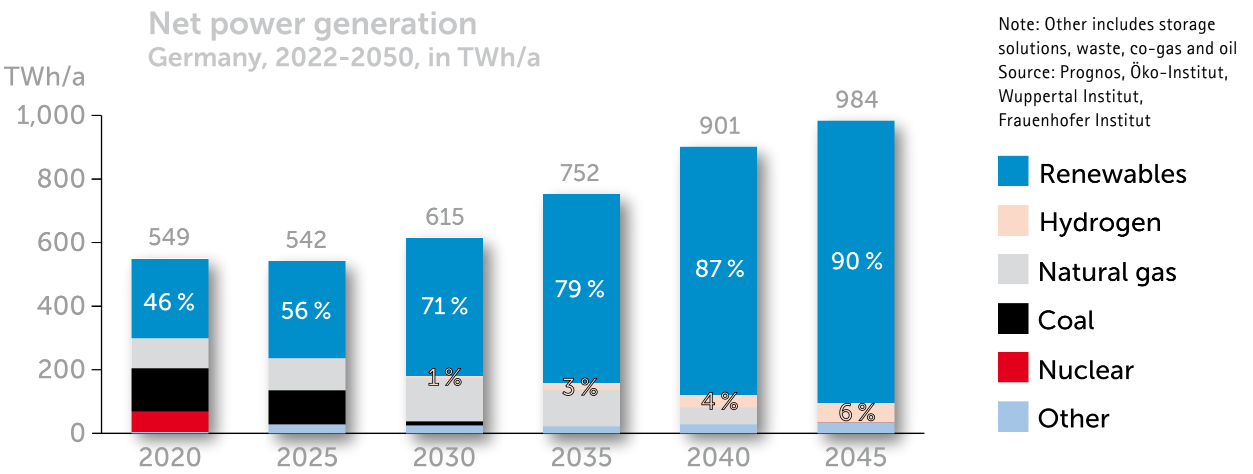


Germany is transforming its energy sector from a major emitter of greenhouse gases to planned net-negative

Whilst Germany has begun advancing in the digitalisation sector, Germany also commences the charge in renewable energy resourcing. Globally, energy consumption is expected to increase considerably in line with rising greenhouse gas emissions in the next few years. According to International Energy Agency (iea) estimates, global electricity demand will increase by approx. 30 % by 2030 and 80 % by 2050 compared to 2020. In China, Brazil and India alone, energy consumption is forecasted to increase by 20-45 % by 2030. According to current policy actions, Chinese CO_2 emissions in the energy sector are projected to peak between 2025 and 2030 and to continuously rise in Brazil and India by 2-3% and 30-40 % by 2030 respectively.

Germany is taking a fundamentally different approach and is leading the way with ambitious climate targets for 2030 and beyond. However, the current energy crisis demonstrates clearly that goals and their implementation must be contrasted. Comparable with global developments, German energy consumption is expected to significantly increase up to 984 TWh in 2050 (see figure 12), primarily due to extensive electrification as well as the production of green hydrogen. The main drivers of electrification are the additional demand in the transport and heating sectors. Examples are the increasing use of electric vehicles and the replacement of conventional heating systems with electric heat pumps, of which it is estimated that there will be 14 million in 2045 (Prognos, Öko-Institut, Wuppertal-Institut, 2021). The production of green hydrogen by means of electrolysis leads to a demand increase of up to 150 TWh by 2045 (Prognos, Öko-Institut, Wuppertal-Institut, 2021).

Fig. 12 **Overview of net power generation by 2050 in Germany**



Furthermore, the German electricity-mix plans exhibit a clear shift towards a complete dominance of renewables and the phasing out of conventional power generation. Driven by the expansion of solar PV as well as wind onshore and offshore, the share of renewables will rise to 90 % in 2045. The remaining 10% will be provided by the use of green hydrogen based on renewable energy sources as well as energy storage solutions. Hydropower will remain at a constant level due to geographical limitations in Germany, while biomass and biogas will slightly increase.

This contrasts with the significant decline in conventional energy sources. The last nuclear power plants were originally planned to go off the grid at the end of 2022; however, due to current energy developments due to Russia's invasion of Ukraine, these are set to be in reserve use until 2023. The last coal-fired power plants will cease operation between 2030 and 2035. Natural and liquid gas will gain relevance as a bridging technology until 2030, increasing by a factor of 2.5 compared to 2020 and then being completely replaced by renewables and renewable-based generation by 2045.

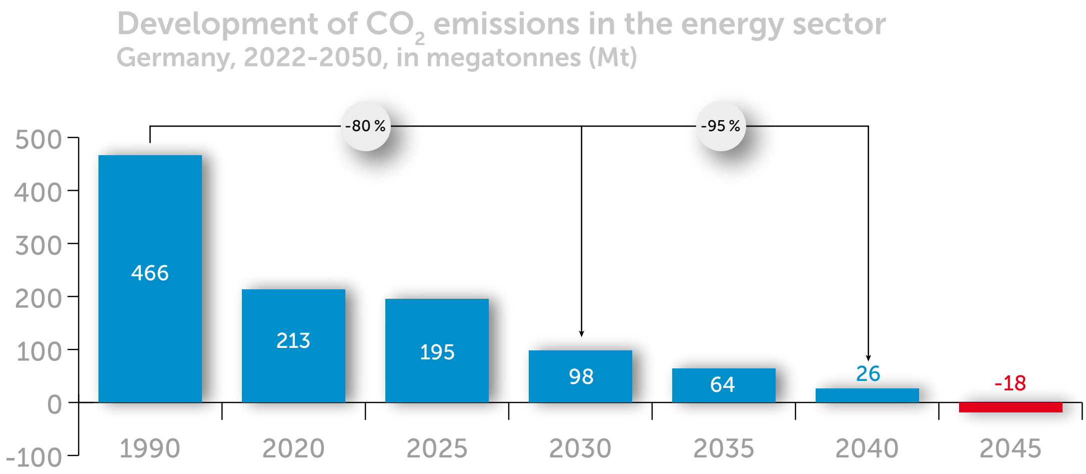
The consequence of the ambitious expansion of renewable energy sources results in a complete decarbonisation of the energy sector by 2045 while providing negative emissions. In line with the climate targets of the German government, the energy sector will experience a reduction of greenhouse gas emissions of 80 % by 2030 and 95 % by 2040 compared to 1990, respectively (see figure 13). The achievement of climate neutrality is projected for 2043.

The use of complementary measures will lead to net-negative emissions by 2045. An example of complementary measures is the currently discussed use of carbon capture and storage (CCS), e.g. in the context of biomass and biogas in power generation. The energy sector is thus changing from being a leading emitter of greenhouse gases to an important lever for global climate protection.

With the ambitious goals of the German federal government for renewable energy sources, significant challenges arise – moving away from a central power supply system to a decentralised one. Further evidence that the demanding goals can only be achieved through digitalisation. The possibility of a shift towards decentralised power supply systems is enabled through the results of digitalisation, such as energy load management systems that achieve constant balance in the system.

Adding this energy mix development to the increasing share of digitalisation needs in Germany accelerates the sustainability of digitalisation measures.

Fig. 13 **Overview of CO_2 emissions in the German energy sector by 2050**



Creating a sustainable digital ecosystem requires a collaborative effort from all stakeholders

Although Germany is advancing on the digitalisation and climate change trajectory, launching Germany into the next phases requires continuous input from all stakeholders. Policy makers can make the required regulatory environment that industry needs, but the industry needs to take responsibility in educating the German policymakers to showcase the positive impact digitalisation has on sustainability.

The political ambitions must centre on strengthening and developing Germany as a key infrastructure hub and data centre location. Strategically, data centres are the centrepiece of the digital transformation. To develop this further, German policymakers need to develop an awareness of the competitive drivers that make a data centre strategically attractive. Currently, the Nordic markets have the edge in Europe through the colder climate and its regulatory approach to investment parameters. These are translated into investment into sustainable energy sources and overall lower energy prices as well as beneficial tax treatment, as, for example, seen in Sweden, where a 97 % tax cut on electricity for data centres was implemented in 2016 (Judge, 2016). German policymakers also can incentivise with lower levies. Combined with lower levies and Germany's strength in connectivity networks, Germany could position itself as a key hub for the data centre industry.

With the additional focus on sustainable energy sources, the move to sustainability can accelerate the development of renewable energy sources. Not only will this benefit the broader digitalisation infrastructure, but it will positively impact all industries in the German economy.

These policy ideas can only be brought forward effectively if the underlying infrastructure is as developed as it can be. Research on data centre topics and the broader infrastructure assets will contribute to achieving the required quality for Germany to adopt a leading role in digitalisation and sustainability. The consolidation of fibre networks in Germany is setting the tone for further development that other infrastructure assets can follow as an example.

Infrastructure operators need to think about setting up clear frameworks in their industries that can articulate the needs clearly to outside parties. One example is the GAIA-X project, where data centre operators align on European-wide standards. Within the framework of this project, "representatives from business, science and politics are developing a sustainable contribution to the design of the next generation of a European data infrastructure at an international level". The goal here is a sovereign and interconnected data infrastructure that promotes innovation. Through this organisational structure, there is a constant flow of information between all stakeholders, but also within the industry itself.

Examples such as these can be used to derive organisational and process patterns for policymakers, which the legislature, in turn, must use to maximise efficiency by cutting through red tape and improving interdepartmental collaboration. These "speed boat" ideas enable Germany as a whole to respond more efficiently to the changing environment.

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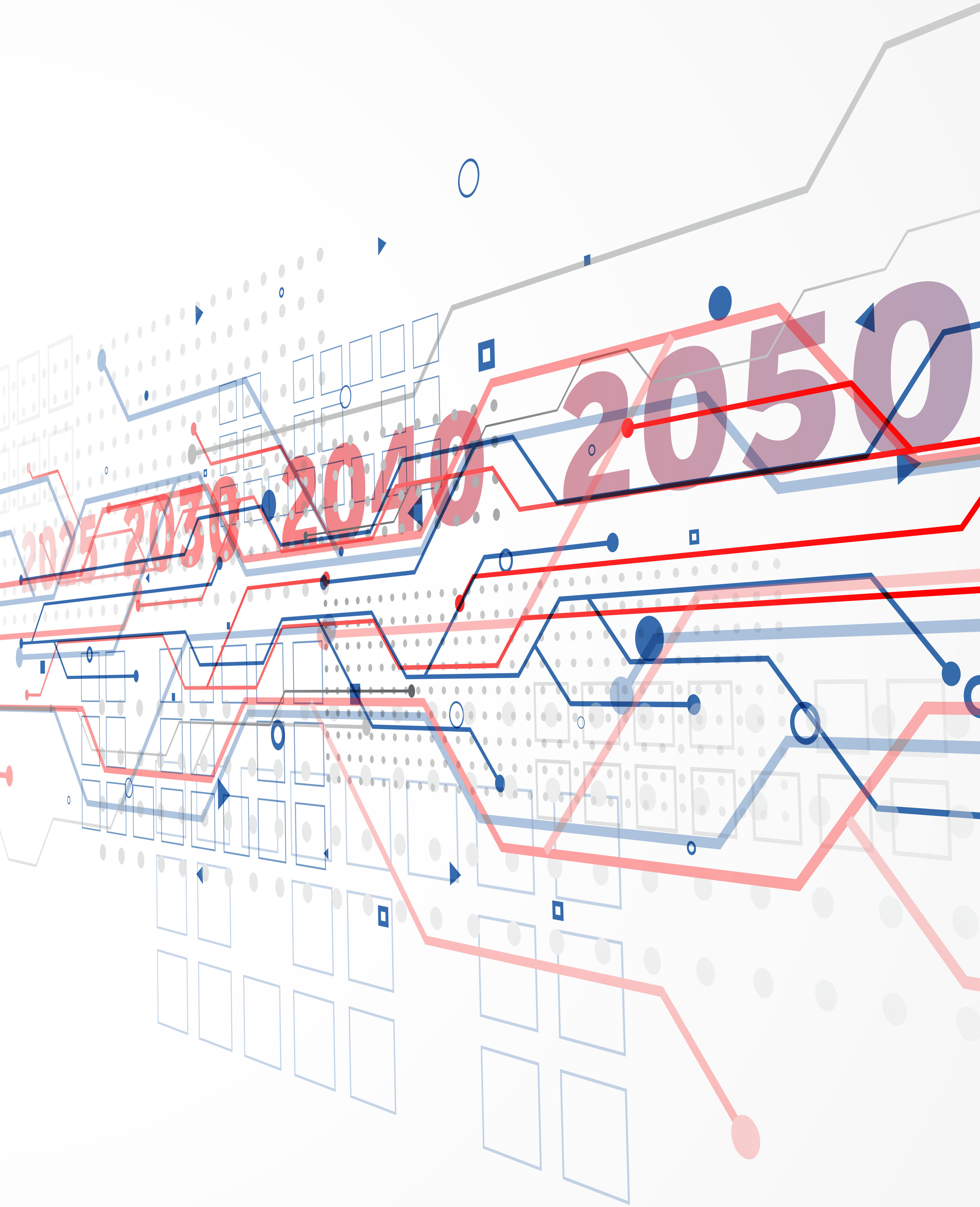
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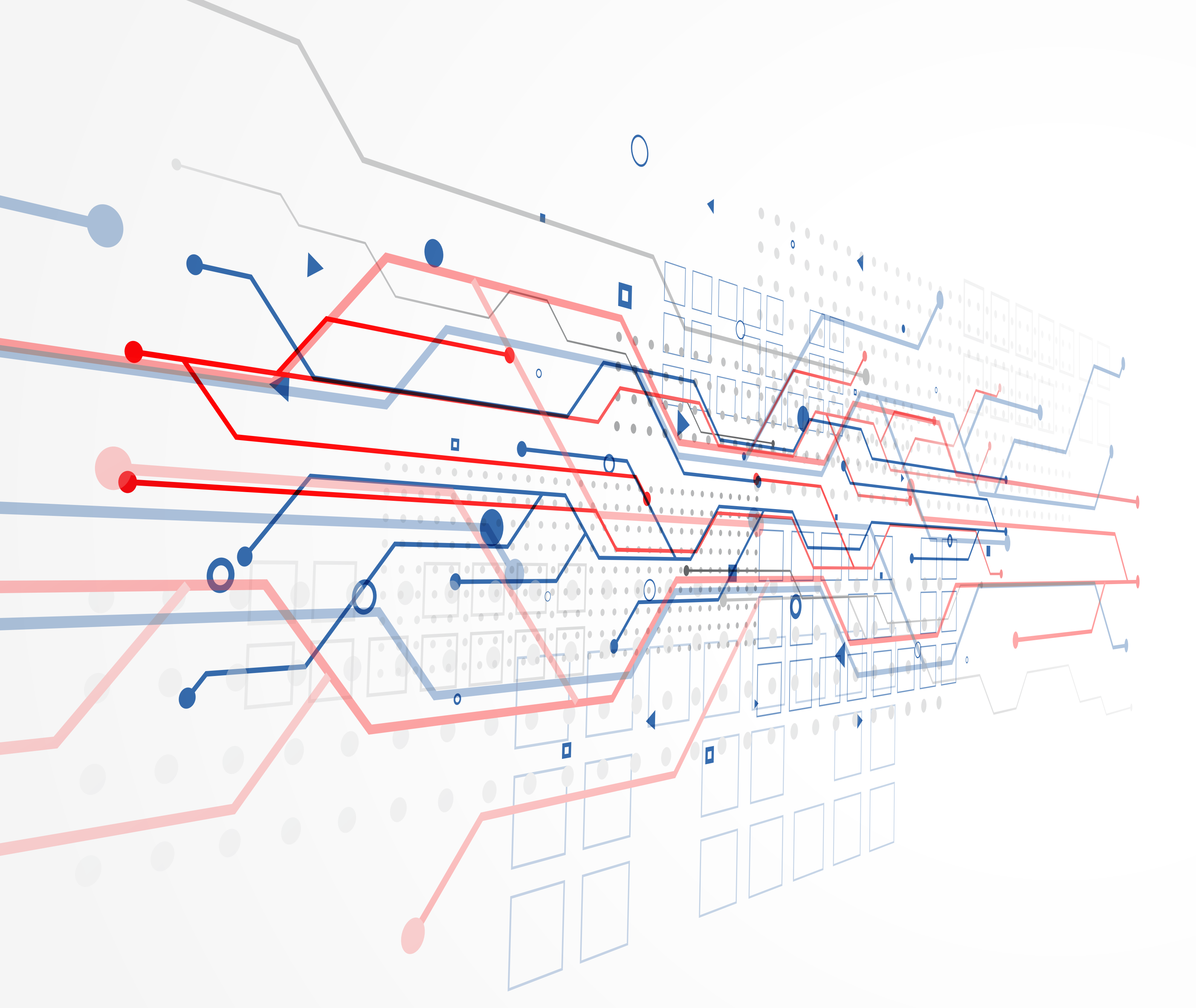

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