Shaping sustainable digitisation

A discussion paper from the German Environment Agency

German Environment Agency

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Content

List of figures

List of tables

List of abbreviations

AR	Augmented Reality
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMVI	Federal Ministry of Transport and Digital Infrastructure
BMWI	Federal Ministry for Economic Affairs and Energy
BNE	Education for Sustainable Development
BSI	Federal Office for Information Security
ERP	Enterprise Ressource Planning Software
GEOSS	Global Earth Observastion System of Systems
HDE	The German Retail Federation
IKT	Information and Communication Technologies
INSPIRE	Infrastructure for Spatial Information in the European Community
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information technology
KI	Artificial intelligence
KMU	Micro, Small and Medium-sized Enterprises (SMEs)
MR	Mixed Reality
ÖPNV	Local public transport
PKW	Passenger Car
REACH	Registration, Evaluation, Authorisation and Restricion of Chemicals (EU-Chemikalienverordnung)
SDG	Sustainable Development Goals (Agenda 2030)
SOS	Sensor Observation Services
UBA	German Environment Agency
UN	United Nations
UNESCO	United Nations Educational Scientific and Cultural Organization
VDI	The Association of German Engineers
VR	Virtual Reality
WBGU	German Advisory Council on Global Change
WLAN	Wireless LAN

Introduction

Digitalisation is already spreading throughout all areas of our society. Rapid development in digital technology such as artificial intelligence, big data and virtual reality will, moreover, mean an ever greater role for digitalisation in the future. It is therefore essential that the societal debate on digitalisation not be limited to technical or economic aspects, but include a comprehensive consideration of the ecological and social impact (such as increasing threats to privacy). Alongside the widely discussed issues of data protection and ethical and social questions (for example regarding transparency and whether we should allow automated decision-making systems), we must also consider the potential direct and indirect ecological impact and its significance for environmental policy. Digitalisation offers potential for environmental and climate protection and resource conservation, but also poses risks. Failing to consider or underestimating those risks will likely result in digitalisation having a negative overall environmental impact. If we want to prevent this whilst harnessing the opportunities and positive effects of digitalisation for the environment, we must consider the environment and sustainability from the outset in digital processes and take account of them in practice.

All stakeholders in society such as companies, scientific and educational institutions and civil society organisations have the task of dealing with the many different aspects of digitalisation and developing the necessary skills and capacity. This also applies to the Federal Government and its relevant ministries and subordinate authorities. The German Environment Agency (UBA) therefore also needs to systematically consider the opportunities and risks of digitalisation for the environment in its work. In line with its motto "For our environment", the UBA seeks in this discussion paper to show, in selected areas, the current challenges posed and opportunities offered by digitalisation for health and the environment, and the resulting approaches and research needs in terms of forward-looking policy advice for the German Environment Agency. This paper is thus designed to help ensure that digitalisation is shaped and harnessed in a way that promotes the development of a green and sustainable society.

1

Current situation

Current situation

Digitalisation is a current megatrend that is reflected in developments such as the digital transformation of manufacturing, e-commerce, sharing platforms, the Internet of Things (IoT), autonomous vehicles, big data, artificial intelligence (AI) and blockchain applications such as cryptocurrencies. Digitalisation is fundamentally changing how we live, learn, work and communicate with each other, how we produce and consume, and how we organise ourselves as a society. It is therefore posing new political, economic, social, ecological, cultural and ethical challenges that are currently the subject of a broad debate in society. However, the positive and negative effects of digitalisation on the environment and resources are currently still not sufficiently addressed in the debate. A number of studies (WBGU 2019) have already shown that digitalisation is accompanied by both opportunities for environmental protection that should be taken and risks that require environmental policy solutions. Environmental aspects must be considered as integral part of digitalisation. Digitalisation often involves fundamental changes to production structures, infrastructure and patterns of consumption. Sustainable solutions can thus be chosen from the outset.

Digitalisation can on the one hand be used directly for environmental protection and for improving environmental policy. For example, the information availability for environmental policy can improve e. g. that of satellite data, or digital solutions can make law enforcement easier and more effective for all parties involved. Digitalisation also opens up a whole range of new options for businesses and private households. As economic, production, trade and consumption processes become increasingly digitised, interconnected, and changed e. g. by the growing spread of Internet of Things, this offers wide-ranging opportunities for optimising processes and increasing efficiency. Such opportunities can help to reduce the use of resources (raw materials and energy) and the corresponding impact on the environment and human health. Moreover, not only are traditional value chains and processes being digitised, but we are increasingly seeing the emergence of completely new (additional) markets with new value chains, which are having their own impact on people and the environment. As part of new augmented, mixed and virtual reality, for example, new devices are coming onto the market that can raise public awareness and understanding of environmental problems.

On the other hand, with digitalisation the demand for Internet-capable products, sensors, network infrastructure and data centres is increasing, and thus the consumption of raw materials and energy during production and use. This applies in particular to the demand for precious and special metals, the additional energy input for the development of the relevant infrastructure and the operation of greater data centre capacity (DE-UZ 2015/161). The latest estimates are that 1.7 billion connected household appliances will be in use across Europe by 2025, in addition to a growing number of conventional information and communication technology products such as smartphones and personal computers (Hinteman et al. 2018). At European level, this trend will, in the long term, require additional energy of more than 70 terawatt hours per year – the current energy consumption of all private households in Italy combined.

In summary this means: in order to use the environmental benefits of digitalisation and to avoid potential negative effects as far as possible, we need forward-looking policy, with action at an early stage before negative environmental effects emerge (Langsdorf et al. 2014). Digitalisation is not an end in itself; this development should be guided by sustainability goals such as those set out in Germany’s National Sustainable Development Strategy, published by the Federal Government (Federal Government 2016). The German Chancellor Angela Merkel has clearly defined the direction for modernisation in Germany. “Basically, we have with the principle of sustainability a definition, and an indicator, of what progress in our society means.”

2

Establishing digitalisation as a new focus of environmental policy

Establishing digitalisation as a new focus of environmental policy

Politicians have recognised the importance of the digital transformation. The increasing significance of digitalisation is reflected in the "Digital Agenda 2014–2017" (Federal Government 2014). This comprises seven measures from infrastructure development and data security to the digital economy and digital working, and was accompanied by a "Digital Strategy 2025" (BMWi 2015). The coalition agreement signed by the Federal Government (CDU; CSU; SPD 2018) emphasises the importance of digitalisation, and this has translated into the establishment of the post of Minister of State for Digitalisation at the Chancellery. In 2018, the Federal Government also published a "National Artificial Intelligence Strategy" (Federal Government 2018), and it is planning to present a comprehensive blockchain strategy in 2019 (*Bundestag Drucksache* [parliamentary paper] 19/7286). At a European level, the European Commission launched a Digital Single Market Strategy in 2015 and, in May 2017, published a mid-term review of that strategy (European Commission 2017). In May 2019, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) published key points for its digital policy agenda and made some initial proposals on how green, environmentally sound and climate-friendly digitalisation might look. The plan is to launch a broad debate and to pass a digital policy agenda for the environment by the end of the year (BMU 2019b).

Politicians have thus recognised the great overall and general impact of digitalisation as a key issue for the future. However, the risks and opportunities posed by digitalisation for environmental protection in particular have to date rarely been explicitly mentioned in programmes and strategies. To help remedy this omission, the UBA is specifically exploring the opportunities and risks of digitalisation for sustainable development. The following questions are shaping this UBA reflection on digitalisation and environmental protection:

- **What new trends are emerging as a result of digitalisation?**
- **What cultural, social and economic change do they involve?**
- **What opportunities does digitalisation offer for accelerating and shaping the process of transformation towards a sustainable society?**
- **What other environmental impact, ecological risks and resource requirements, and also potential opportunities and environmental benefits, are associated with digitalisation?**
- **What strategies and tools could be used to achieve green digitalisation and conserve resources?**
- **What strategies and tools could be used to drive forward environmental and resource protection through digitalisation and what societal change would this require?**

3

“Strategic Foresight” for the early detection of potential opportunities and risks of digitalisation

“Strategic Foresight” for the early detection of potential opportunities and risks of digitalisation

Digitalisation is one of the megatrends of today’s world. Megatrends are by definition trends that fundamentally change society and the economy (Behrendt et al. 2015). A megatrend is made up of and defined by a whole range of different individual trends. For example, the megatrend digitalisation involves the increasing connectedness of products, things, services and social interactions, ever faster processors and higher Internet speed, and new technical possibilities such as the use of big data in many different areas and increasing virtualisation (for example in e-sports).

The various trends within digitalisation differ in their speed, their degree of impact on society and the way in which they affect the environment. Digitalisation is therefore a highly dynamic field of research. One challenge is to keep track of all new developments in digitalisation and to identify as early as possible those developments that pose a risk or opportunity for the environment and thus require an environmental policy response.

The tool used by the UBA to systematically review all the many developments in digitalisation and pinpoint those with a significant impact on the environment is “Horizon Scanning”. Horizon Scanning enables the early identification of future trends when they are very new and there is as yet no research into their environmental impact. As the development of the mobile phone since the 1990s has shown, supposedly niche technologies can rapidly become mainstream, fundamentally change our way of life, and both harm (for example coltan mining) and potentially create opportunities for the environment (for example through the sharing economy).

In particular, socio-economic or socio-technical changes that have an indirect impact on the environment are difficult to detect, but require timely political action. The complexity shows the following example, when changes in patterns of consumer behaviour as a result of digitalisation are leading to greater mobility and thus indirectly harming the environment. The aim of such Horizon Scanning processes is therefore to identify as early as possible all new developments in digitalisation that are relevant to the environment and have not yet been (systematically) addressed in order to make them available for further processing in UBA and BMU.

The following aspects of digitalisation are currently being explored by the UBA as part of Strategic Foresight, as our analyses show that they involve a particularly large number of opportunities and risks for the environment.

- **Artificial intelligence (AI) and sustainability**
- **Blockchains**
- **Virtual reality (VR) and augmented reality (AR)**
- **The platform economy: the monopoly as a business model in e-commerce**
- **Behavioural control by algorithms in the digital age**
- **Robots beyond production facilities**
- **Technologisation and digitalisation of the health sector**
- **3D printing**

Figure 1

The impact of AI on society

Technological Singularity

The “technological singularity” is a theory according to which at a certain point in time, machines will rapidly improve themselves through Artificial Intelligence (AI).

Futurist Ray Kurzweil assumes that that by 2029 computers will be more intelligent than humans and reach singularity.

The four industrial revolutions

End of the 18th century
Transition from agricultural to industrial society

Beginning of the 20th century
Mechanisation, widespread electricity and mass production of goods.

End of the 20th century
Digital revolution through digital technology and computers

21st century
Second wave of digitalisation through the internet

Education system

Educational opportunities are becoming increasingly digital (e. g. teaching through MOOCs or learning platforms such as moodle)

Education system will offer more lifelong learning opportunities that can be combined with full-time work.

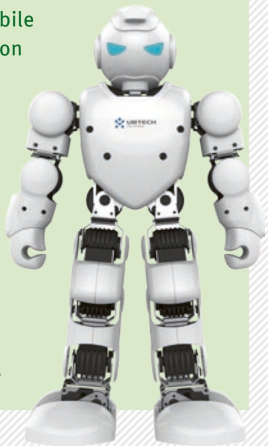
Robotics

1962
The company Unimation introduces the first hydraulically operated industrial robot

1970
The first autonomous mobile robot is developed at Stanford Research.

1997
The first mobile robot lands on Mars.

2017
The UN discusses a ban on autonomous weapons, so-called killer robots



Social systems

Replacing workers with robots would drastically reduce tax revenues, so MEP Mady Delvaux, for example, proposes a “robot tax”.

For the loss of wages, a universal basic income is being discussed. First attempts are taking place in the Netherlands, Kenya, India, Switzerland, Finland and France.

Opinions from the Tech industry

“AI is far more dangerous than nukes.”
Elon Musk

“Success in creating effective A.I. could be the biggest event in the history of our civilization. Or the worst. We just don’t know.”
Stephen Hawking

“AI is on the verge of making our lives more productive and creative.”
Bill Gates

Source: Debating Europe

The example of AI shows how rapidly political processes can need research findings. The risks and opportunities that AI has for the environment and for sustainability as a whole have not yet been comprehensively explored in research. At the same time, there is currently a broad debate in Europe on innovation and funding policy, and this is set to determine the future direction of AI. From an environmental perspective, this is an opportunity to shape the AI of the future in a socioecological way. Overall, there is the aim to assess all developments in AI in terms of their contribution to the global sustainable development goals (SDGs) set out in Agenda 2030 (G. A. Res. 70/1 2015). AI applications that are not compatible with those goals should not be an option. In this way, findings from Strategic Foresight could feed straight into the political debate.

4

Digitalisation action areas for environmental policy

Digitalisation action areas for environmental policy

Since digitalisation affects in almost all areas of society, digitalisation can only be understood as a cross-cutting environmental policy issue and addressed jointly by politics, business, research and civil society. This places high demands on government action, which requires coordination not only within the Environment Ministry but also across and between other federal ministries and all other political, business and social stakeholders.

Digitalisation is highly dynamic, with new innovations constantly emerging, new products coming onto the market and new social practices being established. It is therefore important to recognise the changes caused by digitalisation at an early stage and to constructively and critically evaluate and monitor them from an environmental and resource perspective on an ongoing basis. In line with the precautionary principle, negative environmental effects of digitalisation must be avoided from the outset and digital change must be managed in such a way that it is compatible with sustainability goals. Opportunities offered by digitalisation for environmental and resource protection should be used by as many people as possible and as intensively as possible.

It is the role of environmental policy to design the heart of digitalisation, information and communications technology (ICT) and the associated ICT infrastructure in a way that is green and resource friendly (4.1). Progress in ICT also offers new potential for infrastructure control and (inter)connection (4.2).

Digitalisation is also changing the way we produce, consume and do business (circular economy). We need to explore the opportunities of digitalisation for a circular economy (4.3) critically to monitor the digital transformation of manufacturing from an environmental perspective (4.4), leverage the potential of digitalisation for corporate environmental management (4.5) and harness the opportunities for green consumption 4.0. At the same time, we need to correct negative trends in which digitalisation is leading to unsustainable patterns of consumption (4.6).

There are also a whole number of environmental policy areas that are undergoing significant changes as a result of digitalisation, and that therefore require critical monitoring with regard to the risks they pose and opportunities they offer for the environment. Such areas include mobility (4.7), the energy infrastructure (4.8), the chemical industry (4.9), agriculture (4.10) and water management (4.11).

Finally, digitalisation is also shaping knowledge, skills and patterns of behaviour in society. Section 4.12 sets out how environmental education and education for sustainable development can make a difference in an increasingly digitised and digital world.

4.1 Green and low-resource information and communications technology

Progress of digitalisation and further developments

Digitalisation refers to the switch from analogue to digital processes. Under this definition, digitalisation began back in the mid-20th century. In the 21st century, digitalisation is spreading much more widely and rapidly into all areas of life and the economy as a result of the connectivity of devices with the internet. The basis for this development is the digital infrastructure, or ICT. That infrastructure comprises end devices such as smartphones, connected household appliances, industrial robots, and also transmission technology and networks, various sensors and a large number of data centres.

Smart products and services are increasingly spreading throughout society, science and research, business, and politics, with an ever greater number and variety in use. In 1998, 38.7 percent of households in Germany owned a PC. In 2018, this figure was 90.4 percent. An even more striking illustration of the digital transformation over the past ten years is the number of private households with an Internet connection. In 1998, 8.1 percent of households had an Internet connection. By 2018, this had risen to 92.7 percent.

The example of AI shows how rapidly political processes can need research findings. We have yet to see comprehensive research into the risks and opportunities associated with AI for the environment or sustainability. At the same time, there is currently a broad debate in Europe on innovation and funding policy, and this is set to determine the future direction of AI. From an environmental perspective, there is a chance here to help shape the AI of the future in a socioecological way. Overall, we need to assess all developments in AI in terms of their contribution to the global sustainable development goals (SDGs) set out in Agenda 2030 (G. A. Res. 70/1 2015). AI applications that are not compatible with those goals should not be an option. In this approach, findings from Strategic Foresight could feed straight into the political debate.

Table 1

Information and communications technology in private households in Germany

Information and communications technology	1998	2003	2008	2013	2018
Total households (1000)	36,703	37,931	39,077	40,032	40,596
Percentage of households with ICT					
Personal computer	38.7	61.4	75.4	85.2	90.4
Fixed	–	58.2	62.1	53.3	44.2
Mobile	–	10.7	34.7	65.2	81.2
Laptop, notebook or netbook	–	–	–	–	73.9
Tablet	–	–	–	–	47.5
Printer (separate or as part of multifunctional device)	–	–	–	73.7	75.2
Internet connection	8.1	46.0	64.4	80.2	92.7
Fixed (e. g. DSL or cable)	–	–	–	–	86.7
Mobile (e. g. smartphone or Surfstick)	–	–	–	–	56.0
Telephone	97.6	98.7	99.0	99.8	99.9
Landline	96.8	94.5	89.7	90.5	84.9
Mobile phone; smartphone	11.2	72.5	86.3	92.7	96.7
Including smartphones	–	–	–	–	77.9
Fixed fax machine (separate or as part of multifunctional device)	14.8	20.7	2007	23.8	–
Navigation device	–	–	20.7	46.3	45.8

Source: German Federal Statistical Office

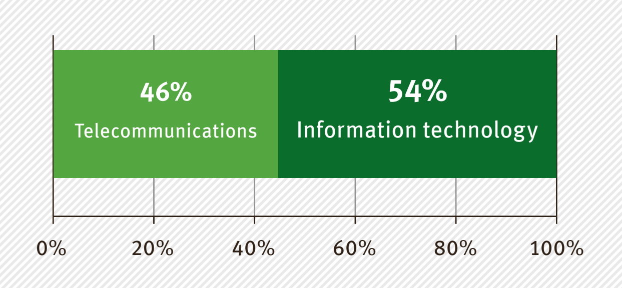
The rapidly growing popularity of smartphones amongst consumers is one indication of the dynamic development of digitalisation. While smartphones did not play a major role in most households in 2013, by 2018 the technology had spread to 77.9 percent of all households in Germany (Destatis 2019).

This development in particular shows just how quickly technological innovations in ICT can spread – and this applies not just to private households but indeed also to the entire infrastructure. Between 2003 and 2013, the area used for information technology (IT) in data centres in Germany increased by 42 percent to around 1.8 million square metres (Hintemann et al. 2014).

In Germany, around eight billion euros are invested in data centres every year (Hintemann et al. 2014). Germany is the largest data centre location in Europe and the third-largest in the world. The ICT sector as a whole currently employs more than one million people in Germany and generates an annual turnover of 228 billion euros – the fifth-highest ICT turnover globally. Turnovers can be broken down as follows: in 2018, the IT sector generated 54 percent of German ICT turnover; the telecommunications sector accounted for 46 percent (PI 2018).

Figure 2

Nationwide ICT turnover in 2018 by sector



Source: Bitkom Research

Currently, the sector is experiencing even higher gross value added than traditional industries such as the chemical and pharmaceutical sectors and mechanical engineering. The pace of digitalisation is often directly linked to innovation in ICT. The key question with regard to environmental impact is therefore how digital value creation can be decoupled from resource consumption. It is not enough to focus simply on the direct and local effects of digitalisation processes. We need a holistic view that also considers the digital infrastructure and its global effects, not least because ICT is now a driver for other sectors of the economy and therefore offers great economic potential but also poses ecological risks.

Current opportunities and risks for the environment

Both the production and operation of ICT and its disposal consume energy and use up natural resources. On the other hand, there is also potential to avoid the use of material (for example digital storage instead of printouts), cut out transport requirements (retrieval of information from any location) and reduce the use of resources by accelerating or optimising processes.

Opportunities for the environment arise, for example, from the fact that the expected increase in the demand for electricity and raw materials can be reduced through intelligent ICT system design and the better utilisation of technology.

All this enables, for example, resource optimisation in household appliances through ICT or energy-optimised use of wireless LAN (WLAN) thanks to resource-on-demand algorithms. A study by the Federal Ministry for Economic Affairs and Energy (BMWi) has shown that algorithms that adapt WLAN network operation to utilisation can enable energy savings of up to 15 percent while maintaining the same quality of service (BMWi 2014).

Another example is potential energy savings through ICT in data centres. Smart devices can, for example, reduce power or provide more efficient cooling for computers, thereby increasing energy efficiency (BMWi 2014).

However, ICT can also have a whole range of negative effects on the environment. This is because the production and use of various ICT components such as terminal devices, servers, sensors and transmission technology are highly energy-intensive. ICT also requires a number of precious and special metals such as cobalt, neodymium, tantalum, silver and gold. These metals are often mined in conditions that are dangerous for both people and the environment in countries with low social and environmental standards. The production of components also takes place in such countries.

In addition, devices have a very short service life. Firstly, this is due to user behaviour. Consumers in Germany tend to replace electronic devices sooner than technically necessary, either because of technical innovations or for other reasons, even if they still work (UBA 2015).

Secondly, the obsolescence of ICT equipment and the resulting increase in waste electric and electronic equipment is another negative effect on the environment. Obsolescence is the natural or artificial antiquation of products or the premature loss of product functionality deliberately caused by business or industry in order to make consumers buy a new product.

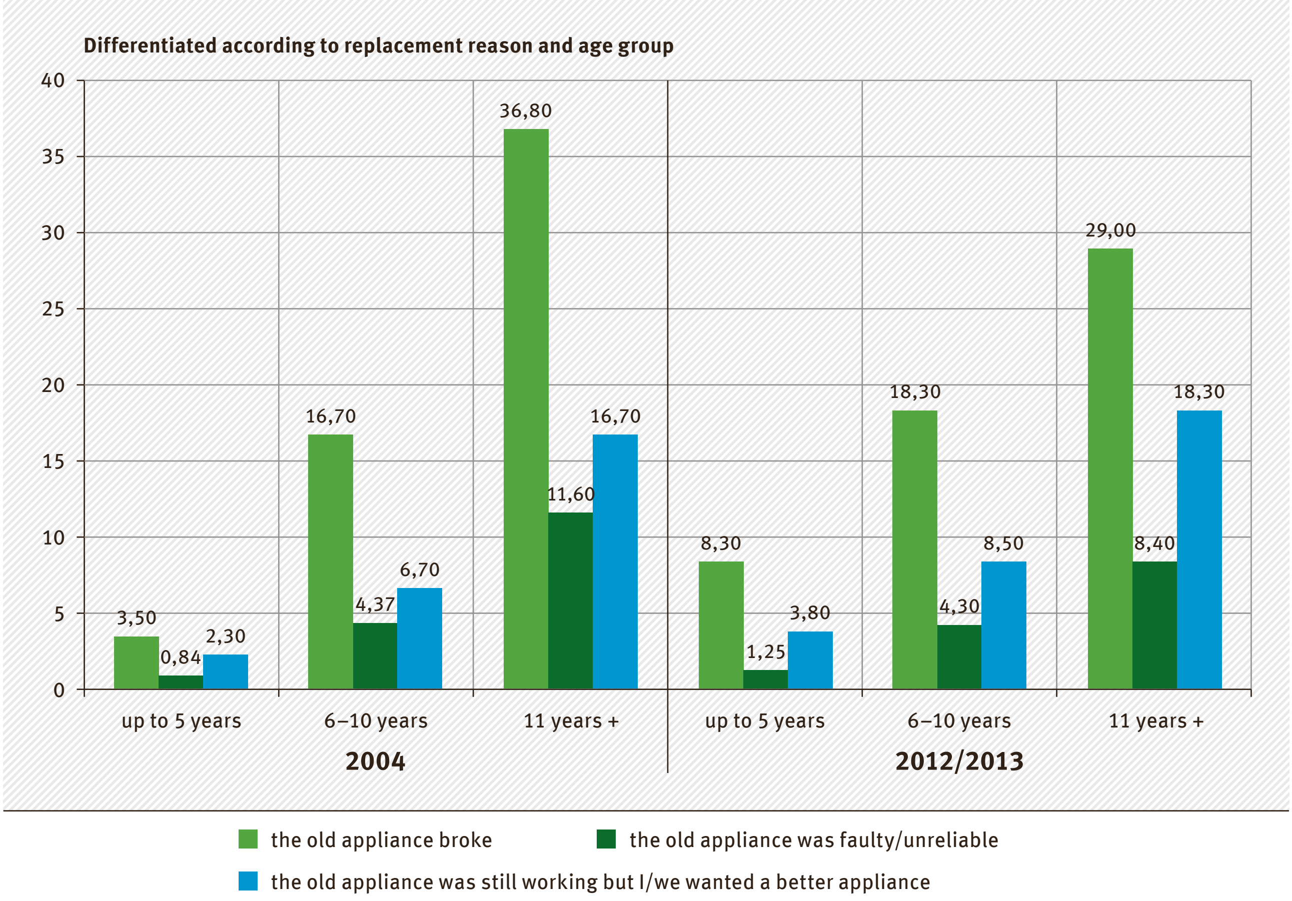
In industry, we distinguish between three different types of obsolescence (UBA 2015).

Material obsolescence: inferior quality materials are used so that products wear out prematurely.

Functional obsolescence: the technical requirements for the product change so quickly that consumers need to buy a new version. For example: a software update limits the functionality of older smartphone versions to such an extent that the old model is no longer usable.

Figure 3

Replacement large household appliances as a percentage of total replacement purchases



2004:n=2712;2012: n=5664 for large household appliances overall

Source: Oeko-Institut, University of Bonn: calculated on the basis of GfK data

Economic obsolescence: the maintenance required to keep the product functioning is not carried out because it is cheaper to produce a new product.

Another negative implication of digitalisation are the rebound effects caused by new digitalisation services, in particular those that facilitate previous activities. For example, easy access to streaming services encourages increased video consumption. Video streaming over the Internet now accounts for around 80 percent of data volume in mobile communications.

The volume of data in Germany has almost doubled within the space of a year. A higher data volume in turn leads to increased power consumption, both in private households and in data centres. If technologies such as augmented reality, mixed reality (MR) and virtual reality are increasingly used in future, this could have an even more drastic impact on the volume of data used.

According to the latest Cisco Visual Networking Index, VR and AR traffic is set to increase twelvefold between 2017 and 2022 (Cisco 2019). All this will require a massive expansion in the telecommunications infrastructure and data centres. A further challenge is that the Internet is not limited by national borders, and data traffic, for example when you send an e-mail, can be global.

We can only estimate the current number of data centres in Germany as there is no data centre register. This makes it more difficult to implement measures and to identify unnecessary redundancy and overcapacity. Initial studies by the UBA have found that utilisation of server capacity averages lies between only five and ten percent. This means that more servers are being operated – and therefore more resources being used for construction, operation and maintenance – than are actually needed for the currently required computing processes. Fewer servers and better utilisation of capacity would be more sustainable (UBA 2018b).

Whether the digitising of processes and structures as well as the connectivity of machines and products is contributing to environmental relief or rather burdens it, can therefore only be assessed if the environmental effects of the production, use and disposal of ICT end devices, infrastructure, networks, microsensors and data centres are all taken into account.

Steps for the German Environment Agency and environmental policy

The UBA sees its role primarily in using its research to highlight the opportunities and risks of ICT and, on that basis, promoting and supporting the use of sustainable ICT. The challenge here is to consider the resource costs of devices, services and ICT infrastructure in all digitalisation achievements and to assess whether these resource inputs justify the benefits of the application or product. Ideally, the benefits should be consistent with the goals of Germany's National Sustainable Development Strategy and key environmental policy requirements such as the Climate Action Plan 2050 (BMU 2019a) and the Resource

Efficiency Programme (ProgRess, Federal Government 2016). For this reason, each new development requires a process of assessment that, firstly, considers whether more resource-saving options are available, and, secondly, whether the benefits of digitalisation for sustainability and climate protection justify the additional use of energy and resources.

The UBA launched a range of projects on "Sustainable ICT" a number of years ago and shall continue to pursue that work. Activities include the development of methods for measuring and evaluating ICT energy and resource efficiency, data analysis for environmental assessments and the development of green alternatives. The areas explored by the UBA in this context include:

- **hardware, software and changes to the technical infrastructure and the potential environmental benefits and burdens**
- **the (global) impact of software on the short life of ICT devices**
- **the environmental impacts of cloud computing and of strong growth in data centres and network infrastructure**
- **environmental labelling for data centres housing the servers of multiple businesses (co-location) and for green software**
- **mobile network infrastructure, in particular the impact of 5G**

The UBA is also actively involved in international and European standardisation initiatives for data centres, and in discussions on ecodesign guidelines for ICT products. This is crucial as it is these technologies that are driving and shaping digitalisation in other fields. The aim is to make the entire life cycle of ICT sustainable.

4.2 Sustainability and digitally connected infrastructures

Progress of digitalisation and further developments

Digitalisation enables the control and connection of infrastructures. Many processes in infrastructure sectors are already automated, such as the management of power stations or waste water treatment plants. A new development, however, is the connection across and between sectors on the basis of comprehensive data collection and evaluation. Thus, ICT is enabling the intelligent control of processes, data and functions across infrastructure sectors (UBA 2018d). New applications include, for example connecting municipal heating to refuse disposal, smart energy grids that adapt to electricity demand, or energy generation in the water supply network. Early warning sensors for flood protection and for measuring air pollution are further examples. For urban space, the term “smart city” is often used to describe concepts that include ICT-based solutions at a municipal level in the areas of mobility, energy, water/waste water and waste. Some local authorities are already considering climate, environmental and resource protection projects as part of their smart city strategies. Overall, however, holistic approaches that specifically address environmental protection and sustainability are in the minority.

There is, for example, no discussion of the impact on the energy and resource use of these new technologies, which serve to digitally connect infrastructures. Furthermore, there has to date been little investigation into the actual green potential of ICT and smart control systems for infrastructure development.

Current opportunities and risks for the environment

The smart connection of infrastructures offers great potential for environmental and climate protection.

For example, innovative solutions for the improved control of technical infrastructure can help to reduce energy and material flows and thus the consumption of energy and resources. The evaluation of current (real-time) data enables the analysis of infrastructure use, allowing process optimisation and customised service provision. Cross-sectoral infrastructure connectivity has now become much more important, not least in the context of the energy and the mobility transition. For example, specific concepts are already available for feeding renewable energy into the transport system, or for connecting waste water treatment plants to the municipal energy supply. In order to exploit the environmental potential, however, we need the systematic development and widescale implementation of such approaches. One major challenge here, apart from creating the necessary technical framework, is connecting the various stakeholders and their sector-specific planning cycles and procedures.

Digitally networked infrastructures in different sectors and fields can also help to maintain public service provision in rural areas and thus contribute to equal living conditions in town and country. For example, new, intelligently controlled logistics concepts that combine goods or refuse consignments can improve the availability of goods in rural areas. This approach can also prevent empty runs and reduce the number of supply-only runs.

Digitally connected infrastructures also create opportunities for new forms of direct citizen participation, which for example enable web-based or app-based feedback from citizens in real time, or digital forms of voting. This can improve citizen participation in political decision-making processes.

In an inter- and intraconnected infrastructure future, these different aspects of digitalisation must be brought together, and ecological and social aspects and institutional questions must be considered alongside economic factors. Tailored regional solutions need to be developed for different types of settlement (cities/small towns; peripheral areas) and conditions on the ground (climate, infrastructure, etc.). In addition to data security and access to infrastructure for all population groups, particular attention must be paid to critical infrastructure, the failure or impairment of which would cause lasting difficulties in the provision of basic services, goods or medical care, significantly affect public safety, or have other far-reaching consequences (BSI, n. d.).

Steps for the German Environment Agency and environmental policy

The UBA believes significant action is needed over the next few years to ensure a holistic assessment of the environmental impacts of such concepts for digital connected infrastructures and smart applications on the one hand, and of social impacts and societal implications on the other. Both the positive and negative effects must be examined.

Alongside an analysis of direct and indirect impacts, an assessment of the entire life cycle of infrastructure is needed. Technical infrastructure usually involves considerable investments that can set the course of development for decades. This creates path dependencies and has long-term effects on the environment. Against the backdrop of upcoming infrastructure expansion and redevelopment in many places over the coming years and decades (UBA 2018d), there is a great need for research into the actual impact of innovative infrastructure solutions on energy and resource consumption and whether or how such solutions can adapt to changing conditions (climate change; demographic change).

Infrastructure solutions can only become genuinely smart if they are linked to sustainable, environmentally friendly, green, resilient and participatory concepts.

In ongoing research projects, the UBA is exploring key research questions at different municipal and regional levels and developing recommendations for the federal, state and local governments. The central questions are as follows:

- **How can environmental and sustainability aspects of digitalisation be established for the interconnection of infrastructure sectors in such a way that they genuinely contribute to the green, resource-friendly and climate-compatible development of supply and disposal structures?**

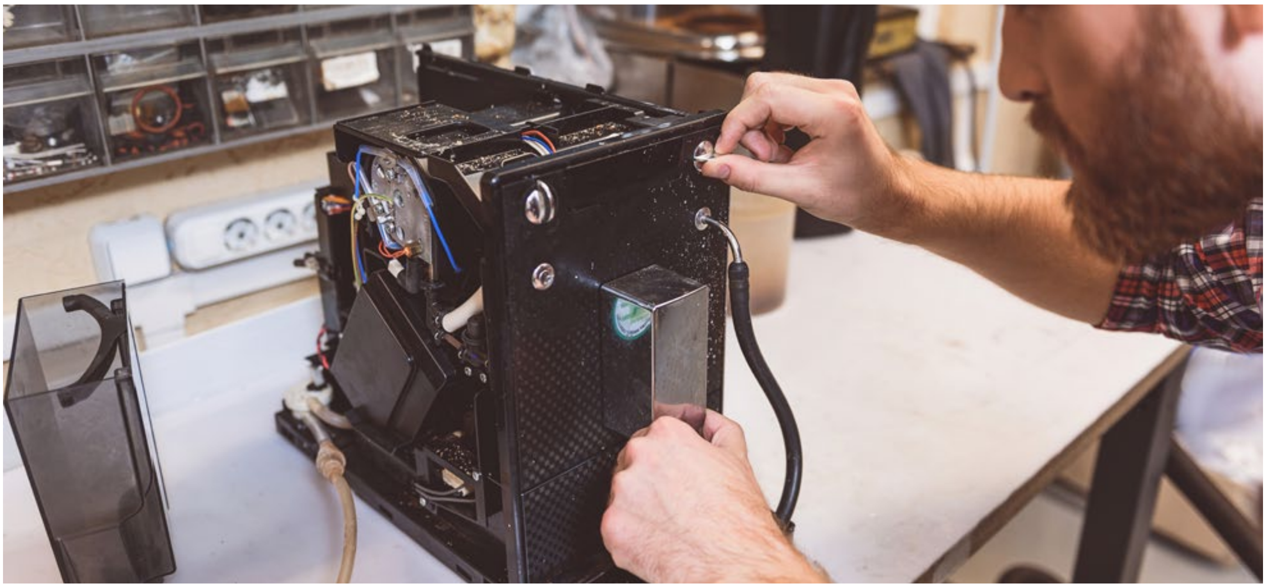
- **How can the digital interconnection of infrastructures help to achieve equal living conditions in town and country and maintain public services in rural areas?**

- **How is the digitalisation of infrastructures changing resource and energy consumption, both through the energy requirements of the technology used and indirectly through rebound effects? Under what conditions do “smart concepts” lead to a reduction in energy and resource consumption?**

- **How must networks, infrastructure and hardware be designed if digitalisation is genuinely to drive greater sustainability? How can we link both new and existing infrastructure in a green and resilient way? What stakeholders and technical, organisational and financial aspects need to be considered?**

The UBA will pursue these questions as it examines in more depth the opportunities and risks of sustainable, connected infrastructure for the environment.

4.3 Digitalisation and environmental protection in a circular economy



Progress of digitalisation and further developments

Saving resources, avoiding waste, using materials as intensively as possible and ultimately reusing or recycling them in the highest possible quality and thus maintaining a closed material cycle: these are the central aims of a sustainable circular economy. A broader understanding of the term circular economy, as it is currently defined in strategic discussions at an EU level, includes much more than waste separation and recycling.

The central principle in a broader understanding of a circular economy is to conserve raw materials in the economic cycle in as green and as resource-friendly and climate-friendly a manner as possible. Such an approach also means maintaining, as far as possible, the value and quality of products and materials after their first use. The entire life of a product is understood as a cycle. That cycle starts at the design stage, continues with production and use, and the extension of product life span through repair, reuse, preparation for reuse, and ends finally with recycling, in which the materials are returned back into the same or similarly high-quality applications. If recycling is not possible, the cycles are extended to other applications or energy recovery. Disposal is to be kept to a minimum.

Digitalisation is already being used to some extent in certain areas of the circular economy, for example in disposal logistics and waste statistics, and here in particular in route planning and quantitative waste management accounting. The focus of digitalisation in the circular economy is on optimising disposal logistics and on sharing information about (used) product materials throughout and beyond the life cycle, right up to the disposal phase.

In any case, it can be stated: Increasing digitalisation is changing material and waste streams. More electronic components, devices and sensors are now in use. Even products that were previously not considered digital, such as smart household appliances, now contain more and more information technology components. All these components become waste after the phase of use and so that they can be recycled new treatment techniques are required to recover valuable materials. Such techniques include sending used products to treatment facilities for used electrical appliances that were not previously classified as electrical devices, such as smart textiles, or removing electronic components from smart washing machines before shredding.

Figure 4

Product life cycle phases in a broader understanding of the circular economy

Source: Accenture

At the same time, digital technologies make it possible to identify and address the associated risks in the circular economy at an early stage. This all means that digitalisation brings both opportunities and risks for the environment.

Current opportunities and risks for the environment

Digitalisation of the circular economy (in the broader sense of the term) both offers opportunities and poses risks for the environment. Considering the entire life cycle of a product from the outset is an opportunity: with new technology, the parameters can be set from the start of product development to make the product more sustainable. For example, production processes can be planned to have less impact on the environment; using efficient 3D printing is one option here.

In the usage phase, approaches can include online sharing models and second-life options, and digital applications allow better coordination and optimisation. All these options allow consumers to resell products or buy used products, and this extends products' useful life. Finally, the logistics of collection and disposal from households to material recycling can be made more sustainable if they are considered right from the development phase and are supported by digital technology.

In disposal logistics, waste and secondary raw material streams can be combined and managed more efficiently, for example with automated logistics and marketing platforms and connected recycling and resource management systems that provide more tailored, efficient and rapid links between the supply of (point of waste generation) and demand for (waste treatment and recycling facilities) waste and secondary raw materials. Smart containers that provide information on bin capacity are just some of the other potential options.

Opportunities offered by digital applications are seen, for example, in the case of various small-scale waste streams or points of waste generation, as they could make the otherwise complex disposal logistics and recycling more economical and thus actually possible. Digitalisation also offers potential for the circular economy in terms of product information: in order to enable life-extending repairs, or targeted disassembly and sorting of complex used products in particular for high-quality recycling, the repairer/disposer/recycler needs the relevant information. Relevant information usually means manufacturer information on the product configuration i. e. the location, quantification and disassembly of components, materials, contaminants and harmful substances in the (used) products or in the waste.

The digital storage and processing of information offers here – with sufficient protection of data privacy – the possibility of centralised product information in "material passports", making all processes from production, delivery and use to disposal more efficient and resource-saving. Challenges here include defining and generating the content to be shared years before the waste phase, and designing the provision of and access to information, which must remain accessible for years. Digitally controlled additive manufacturing processes such as 3D printing can also enable the individual and highly efficient production of spare parts, which will in turn help to extend products' life cycle. Associated with this, there is the challenge of recycling individually produced components properly and to a high quality. Some of the plastics used in 3D printers are not recyclable (UBA 2018a).

Overall, there is still considerable untapped potential for waste avoidance and for more efficient and resource-saving design of closing the loop in material flows. At the same time, we need to assess the rebound effects of digitalisation. One question, for example, is how to minimise the amount of packaging from the growing online retail sector (see chapter "Green Consumption 4.0"). Another challenge is the high-quality recycling of the increasing number of used smart devices and the recovery of precious and special metals.

Steps for the German Environment Agency and environmental policy

If the opportunities of digitalisation in the extended circular economy (in the broader sense of the term) are to be seized and the risks are taken into account, we first need to systematically gain knowledge about the potentials and the risks.

Such findings should contribute both to resource conservation and waste avoidance and to the competitiveness of the German waste management and recycling industry. The starting points in this area are as follows:

1. **Using digital technology to optimise and increase the efficiency of circular processes such as reuse, disposal logistics and recycling.**

2. **Potential options include the separate processing of waste containing valuable substances that is generated in small quantities and whose circular processes can only be made possible and optimised with digitalisation. Other opportunities within the product life cycle include digital manufacturing processes such as 3D printing that use less material, and digitally supported services for more sustainable use such as sharing platforms and second-life options.**

3. **Information flows – both regarding the contents as well as the form of transmission – should be tailored to the users. This extends into the use and disposal phase to strengthen the repair, maintenance, disassembly, treatment and recycling of products.**

The UBA is committed to recognising and promoting the potentials offered by digitalisation for the circular economy and to reshaping digital developments that are not (yet) aligned with the extended concept of the circular economy.

4.4 The digital transformation of manufacturing

Progress of digitalisation and further developments

To date, there has been little focus on environmental aspects, including the impact of digitalisation on security in manufacturing, in the context of Industry 4.0 – the digital transformation of manufacturing. Where environmental impact has been considered, the debate has largely been confined to material or energy efficiency.

The focus of current work and research into Industry 4.0 in Germany is on mechanical and electrical engineering and automation.

The core issues being examined are technical and digital standardisation and the creation of "compatibility" (interoperability) within a given company i.e. between individual divisions, or across divisions and companies in local or global production and service networks. Another focus is on typical Industry 4.0 models and the increasing use of artificial intelligence. Key aspects of these ongoing activities come under the umbrella of "Platform Industry 4.0" or are closely linked to it.

Current opportunities and risks for the environment

Industry 4.0 – the digital transformation of manufacturing – offers new opportunities for process optimisation, intelligent interconnection and data management, as well as for using modern communication technology such as the Internet in order to act flexibly in local to global markets. These new options offered by the shift to Industry 4.0 can also be applied to the environmental sector and present both opportunities and risks.

Process optimisation is one area set to benefit in particular from the use of innovative Industry 4.0 technology and applications. Optimisation potential lies not just in the production process itself but also in all processes related to production, for example waste water or exhaust emissions treatment, in other words traditional environmental engineering, and in power systems and logistics. The wider use of sensor technology in combination with data transmission and processing in real time are at the heart of potential optimisation here: processes can become more transparent, and can be rapidly adjusted and strategically controlled.

The areas that appear particularly promising in the context of Industry 4.0 and the environment are resource efficiency (material and energy), secondary raw materials and recycling, process chains and traceability, chemicals and hazardous substance management, product and consumer information, and data and data management.

One key question is how the "gains" of the digital transformation of industry, for example a reduction in the material or energy input to a process, compare with the "costs" of digitalisation, i.e. the material and energy required for the digitalisation of a process itself, or what this picture will look like in the future. Reliable forecasts on this question are not currently possible, as there is a lack of empirical data from both industrial practice and applied research.

Another point to consider is that environmental findings from practice are still be incorporated into the design of Industry 4.0 models and Industry 4.0-based technology that is still under development. These findings could therefore help shape the course of future developments.

Consequently, it is essential that practical applications of Industry 4.0 for the environment are promoted and initiated alongside research at as early a stage as possible.

However, growing volumes of data and increasing digitalisation also pose risks for humans and the environment. Those risks must be considered from the outset, including in the context of manufacturing.

For example, when using self-learning components as digitalisation progresses, it must always be avoided that gaps in our understanding of or a loss of control over processes can occur. Increasing digitalisation is also involving more and more stakeholders or giving them and others, sometimes unintentionally, access to systems and the opportunity to manipulate processes. Real-time data processing in conjunction with human factors is another issue of growing importance here.

Steps for the German Environment Agency and environmental policy

Overall, there has to date been little or no examination of the environmental question or the impact of digitalisation on security in manufacturing in the context of digital transformation. The UBA has therefore been working for some time on developing practical examples and gaining practical insights into "Industry 4.0 and the environment". The study "Resource Efficiency through Industry 4.0 – Potential for SMEs in the Manufacturing Sector", launched by the VDI Centre for Resource Efficiency in 2016 and supported by the UBA, is one of the first moves in this direction.

Increasing data availability will considerably increase the overall level of information and knowledge about processes, process chains, process states, products, material flows, energy consumption, etc. in all Industry 4.0 areas. Potential for the environment lies in the intelligent aggregation, combination and evaluation of the available data for the environment, resource efficiency and sustainability. In view of the importance of data, the UBA has already launched a research project to explore environmental data in Industry 4.0.

The digital transformation also needs to be seen as a "new potential hazard" in terms of plant safety and accident prevention. This has prompted the Commission on Process Safety (KAS), with the cooperation of the German Environment Agency, to update the SFK-GS 38 guidelines "Combating Interference by Unauthorised Persons", taking into account the requirements of the Seveso III Directive and the Twelfth Ordinance for the Implementation of the Federal Immission Control Act (BImSchV 2000), and the latest technological developments during this term. In 2019, a research project in cooperation with the Federal Office for Information Security (BSI) and the UBA began analysing the effects of Industry 4.0 on plant safety. The project aims to help drive development in safety engineering and to identify appropriate measures for preventing incidents or limiting their impact (best practice examples for safe plant operation).

Connected, flexible and order-based production, typical for Industry 4.0, takes place in international or indeed global production and service networks. The question of standardisation is therefore an important one, which the UBA is exploring accordingly. The UBA has been active on the Standardization Council Industry 4.0 expert panel since 2016 and contributed to the Standardization Roadmap for Industry 4.0, Version 3. It is also monitoring the development of new technology (for example digital twins) and new business models in the industrial sector and exploring the potential and risks of that development.

The UBA will continue to pursue and broaden its work on "Industry 4.0 and the environment" and plant safety in this increasingly digitalised and connected world, intensify cooperation with partners and, through research projects and applications in practice, build up knowledge and understanding that can be used at an environmental policy level as the basis for advanced safety engineering.

4.5 Digitalisation and corporate environmental management

Progress of digitalisation and further developments

Corporate environmental management is part of the overall management of a business or organisation. Processes and responsibilities are organised in a way that meets societal demands for a green approach, complies with legal requirements and allows opportunities and risks for the environment to be identified at an early stage.

Corporate environmental management covers aspects such as energy and material consumption, emissions, land use, waste and waste water. Indirect effects on the environment, such as employees' commute to work and the behaviour of suppliers, are also considered. The objective of corporate environmental management is to improve the flow of information, reduce costs and improve environmental protection. The digital transformation will have a significant impact on all these aspects.

However, although companies are already using automation, mobile computing and software tools for environmental management, application possibilities such as AR and VR, big data, blockchains, cloud computing, IoT and AI are still in their infancy. For example, apart from a few pilot projects with a very limited scope, there are currently no cases for the transfer of environmental data along supply chains using blockchain technology.

Blockchain has the potential to make supply chains more transparent and the flow of goods easier to trace.

Once entered in the blockchain, data cannot be changed, and this prevents manipulation and makes goods easier to trace for all parties involved. In terms of environmental potential, this means that activities relating to the environment at each stage of the supply chain can be recorded in the blockchain, making them more transparent for producers, certification bodies, processing companies, retailers and consumers.

At the same time, blockchains could make it easier to ensure and verify compliance with environmental standards. This applies in particular to sectors such as textiles and cosmetics, in which product labelling has not previously provided transparent information on origin so far. Big data has also only rarely been used for environmental risk analyses. Real-time data on the state of the environment i. e. on water, soil or air pollution or weather and climate data could be used and analysed to outline possible scenarios, for example with regard to climate change.

Even in corporate reporting, which in the financial sector already involves machine-readable interfaces and allows automated evaluation, there is still a lack of standardisation and comparability in environmental and sustainability reporting. Companies of all types and sizes now use enterprise resource planning (ERP) software to manage a wide range of business areas from cost management accounting, accounting and order processing to material handling, production and research and development. The software solutions used to provide digital support for environmental, energy and sustainability management, however, are often stand-alone and have few or no interfaces to businesses' central ERP systems. They therefore do not integrate processes into digital corporate environmental management.

Current opportunities and risks for the environment

On the one hand, digitalisation offers new opportunities for corporate environmental management, in particular with greater transparency and safeguarding of environmental standards. On the other hand, there are possible rebound effects, in particular an increase in resource consumption resulting from the greater use of digital technology in corporate environmental management. The main opportunities for digitalisation are in the following areas:

- **Corporate environmental management accounting**
- **Management of upstream and downstream value chains**
- **Compliance with statutory environmental requirements for businesses**

In environmental management accounting, better measuring and sensor technology and plant connectivity, for example, provide faster access to more data. This allows control-related indicators to be displayed in real time, trends to be recognised sooner, and action to be taken at an earlier stage. For example, you can monitor a plant's energy consumption, immediately detect a higher energy input, and then take the necessary measures.

For the management of environmental aspects in upstream and downstream value chains, blockchain technology in the supply chain could return better data on customers' environmental behaviour and more useful information on environmental impact at the end of a product's life.

This would in turn allow companies to take more targeted environmental management measures and provide consumers with more useful information on environmental protection (for example saving fuel when driving). Within companies, digital technology can ensure better compliance with statutory environmental protection requirements.

Better and more rapidly available information on plant status or emissions could allow the more rapid detection or indeed avoidance of limit violations. Direct reporting in real time from plants to authorities would be another potential option offered by the digitalisation of environmental management.

Digitalisation of corporate environmental management could therefore make a significant contribution to a more sustainable Industry 4.0 (see chapter "Digital transformation of manufacturing"). Digitalisation will likely reduce the cost and complexity of introducing, maintaining and obtaining certification for environmental management systems; this should in turn enable such systems to be used more widely.

At the same time, digitalisation will also open up new areas requiring environmental management: it will increasingly be possible to record and take into account local and general shifts in environmental impact and rebound effects as part of corporate environmental management.

One good illustration of this issue is mobile working, in other words a growing flexibility in working hours and workplaces. In some respects, this development brings ecological benefits, but it often also requires more resource-intensive hardware. In addition, mobile working shifts electricity and heat consumption beyond the direct control of the employer, and this can in some cases worsen overall environmental performance. For example, an employer might use green electricity, but there is no guarantee that its employees will do so if they are working largely from home.

Steps for the German Environment Agency and environmental policy

Through research, dialogue and measures to support businesses, the UBA will work both to allow digitalisation to be harnessed for corporate environmental management and to pinpoint areas in which environmental management could reduce the environmental impact and environmental risks of digitised production.

In line with the guiding principle of a sustainable production, the role of the UBA is to analyse the potential opportunities and risks for the environment arising from digitalisation and connectivity, and to develop strategies for harnessing opportunities for development and avoiding risks. Specifically, the UBA will seek an exchange with developers of ERP systems to explore how greater use can be made of such systems to map environmental data, targets and processes and thus how environmental management can be integrated more effectively into central corporate management.

Digital use cases for environmental management are also being identified and developed as part of a research project on environmental management accounting, compliance management, risk management, supply chain management, stakeholder management, production and human resource management.

4.6 Green consumption

Progress of digitalisation and further developments

The digital transformation is not just changing industry; it is also changing market dynamics and consumer behaviour, with various impacts on the environment. The way in which digitalisation changes consumption is known as Consumption 4.0. The Federal Government has defined Consumption 4.0 as "new processes of consumption in which digitalisation has a major influence on how services, preferences, search processes and purchasing decisions emerge or are formed, and on how they translate into practice on the market and in people's everyday lives" [translated from the German original] (Federal Government 2019).

Consumer behaviour at all levels is also changing. One of the most obvious changes in the behaviour of German consumers is in purchasing behaviour. While retail trade reports less revenue each year, e-commerce in Germany is booming. The "Online-Monitor 2019" published by the German Retail Federation (HDE 2019) reported growth of 9.1 percent for 2018. According to the HDE, there are no signs of imminent market saturation. A growing percentage of online transactions now use digital payment methods; the increasing use of encrypted procedures such as cryptocurrencies in particular is increasing demand for computing and thus also for resources and power (de Vries 2018).

Finally, we must also remember that the role of consumers can change with digitalisation. Both the ultra-personalisation of products and new technologies such as 3D printing are increasingly involving the end user in product manufacturing. Consumers are becoming prosumers as the boundaries between production and consumption blur. Consumers are creating their own consumer networks, for example the digital sharing economy in which both services and goods are shared and exchanged, enabling more sustainable consumption. On online exchange platforms, used goods ranging from electrical and electronic items to clothing can find new owners instead of being discarded. This extends goods' useful life and can reduce the need to buy new products. Research by the Organisation for Economic Co-operation and Development has found that 191 million consumers in 28 EU countries engaged in at least one transaction on a sharing platform in the period from May 2015 to May 2016.

Findings by the BMWi indicate that the figures in this area in Germany are particularly high in the mobility and accommodation sectors (BMWi 2018).

The structural, technological and cultural changes in Consumption 4.0 outlined above, alongside other changes associated with digitalisation, are already having a considerable and far-reaching impact on our consumer society and its potential shift towards sustainability.

Current opportunities and risks for the environment

Consumption 4.0 on the one hand offers potential for the wider distribution and use of green products and services. On the other hand, it poses the risk of an increase in resource-intensive consumption. Before we can assess the extent to which consumer behaviour due to digitalisation is having a negative or positive effect on the environment, we need to understand user behaviour: the impact of Consumption 4.0 depends in part on how consumers behave. The constant availability of products or new marketing methods such as personalised advertising can lead to a rise in consumption.

Yet digital platforms can also improve how to find sustainable alternatives and make production processes more transparent, whilst digital environmental labels, for example quick response labels for smartphones, can encourage less resource-intensive consumption. Smart devices can shift consumer behaviour in private households to reduce energy and water use. Here too, however, it must be remembered that smart devices also require digital technology, and the resources required for that technology and its impact on greenhouse gas emissions need to be taken into account. The BMU has launched various “nudges” to encourage energy saving in private households, for example a list of technologies that make it easier to switch off standby devices (BMU 2016).

The sharing economy also offers potential for sustainable Consumption 4.0. Digital peer-to-peer platforms, for example, enable private car-sharing, the sharing of everyday items, or even the sharing of living space. However, this only applies if the sharing platforms are rooted in sustainable consumption (4.0). Any cost-benefit analysis in Consumption 4.0 must therefore always take account of actual user behaviour and use this as a basis for weighing up opportunities against risks to the environment.

Steps for the German Environment Agency and environmental policy

The options established to date for political and policy impact are reaching their limits as we seek to promote and achieve sustainable consumption within society. An understanding of user behaviour and how e-commerce works will help to create the necessary environmental policy framework and incentives. We need to continue to provide consumers with a strong knowledge base on sustainable Consumption 4.0. The Federal Government has also launched a National Programme on Sustainable Consumption. In the areas of mobility, food, living and the home, work and the office, clothing, and leisure and tourism, the Programme is developing key environmental policy ideas and practical approaches to more sustainable consumption. These include strengthening research in this field (Federal Government 2017). The UBA’s main focus is therefore on studies on the impact of digitalisation on levels of consumption and consumer behaviour; on changes in consumption and lifestyle; on opportunities for consumer information, education, training and advice, and on environmental labelling in e-commerce.

Both environmental impact and risks and the opportunities need to be established and evaluated to allow recommendations for sustainable product and consumer policy on this basis. Current projects are looking at issues such as new digital consumer skills, digital and social innovations for sustainable consumption, and consumer sufficiency. Another aspect being explored is greener e-commerce scenarios with resource conservation, repairability and reuse in the context of growing digitalisation.

4.7 Sustainable mobility and Logistics 4.0

Progress of digitalisation and further developments

Mobility and logistics are undergoing radical change due to digitalisation. In the field of individual mobility, these changes include various digital mobility services such as IT-assisted sharing services (car-sharing, bike-sharing and scooter-sharing), app-based on-demand transport services (ride-sharing, ride-hailing and carpooling) and AI-based fleet management in local public transport. In Logistics 4.0, big data, AI, IoT and ICT are digital trends which change logistics processes.

For example, big data is now used to connect logistics processes. In the field of IoT and AI, this can be seen in devices with autonomous intelligence such as cameras and detectors, and assistance systems in vehicles.

Another area of Logistics 4.0 is cyber-physical systems, in which mechanical components are connected over networks and ICT. Potentially the most far-reaching change in this area of mobility and Logistics 4.0 is autonomous driving.

Table 2

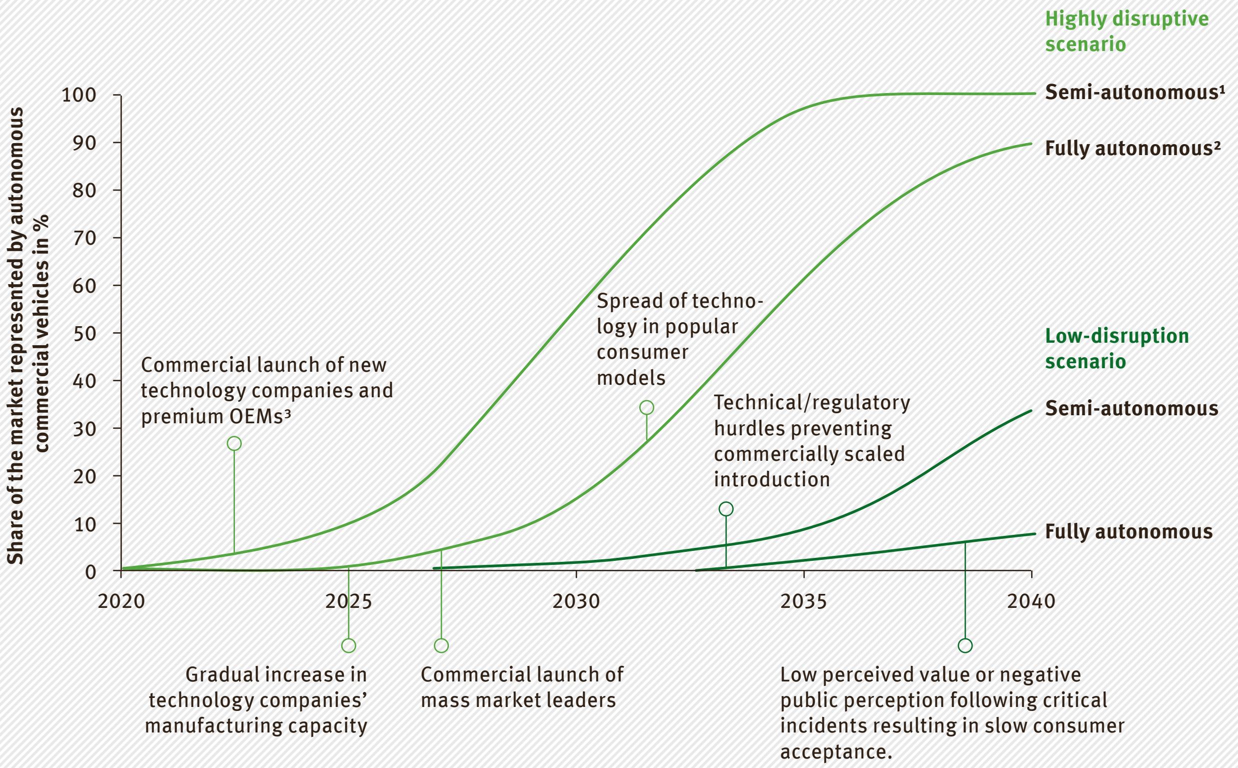
The stages of automation

Automation of driving	Automation level tasks
Fully automated	The system performs various tasks in line with the application. The driver can (but does not have to) take over control of driving.
Highly automated	For the most part, the system undertakes all tasks. The driver does not need to monitor the system. However, the system can prompt the driver to intervene.
Semi-automated	The system performs tasks for a certain period or in specific situations. The driver monitors the system and must be ready to intervene.
Driver-only	The driver performs all functions all of the time.

Source: The stages of automation as defined by the Federal Highway Research Institute (BMVI 2015)

Figure 5

How many new cars could be fully autonomous by 2030?



Factors in disruption scenarios
Regulatory challenges Safe,
reliable technical solutions Consumer acceptance,
willingness to pay

High disruption
Rapid
Comprehensive
Enthusiastic

Low disruption
Gradual
Incomplete
Limited

[1]Semi-autonomous car: The driver sometimes takes control.
[2]Fully autonomous car: The vehicle has full control
[3]Original Equipment Manufacturers

Source: McKinsey

An impact study by the Victoria Transport Policy Institute (Litman 2019) has found that the effects of autonomous driving on cities as well as on transport users could start to be felt as soon as the 2020 to 2030 period. Just to what extent, however, is difficult to estimate at this stage. The consultancy firm McKinsey has created two scenarios of how autonomous driving could develop in future: a high-disruption and a low-disruption future scenario. In the low-disruption scenario, fully autonomous passenger vehicles will account for less than five percent of all vehicles worldwide in 2030. In the highly disruptive scenario, the global market share of fully autonomous passenger vehicles will be 15 percent (Gao et al. 2016).

The effects of digitalisation are already being felt in mobility and logistics; digital mobility services and options are changing individual mobility.

In urban areas in particular, mobility is becoming less dependent on owning your own vehicle as private cars are replaced with digital access to mobility services. According to the mobility report "Mobility in Germany" by the Federal Ministry of Transport and Digital Infrastructure (BMVI), 14 percent of all households in German metropolis have at least one person who is registered with a car-sharing organisation, even if this is to date largely an urban phenomenon. The same applies to owning a car: the report found that 42 percent of households in German metropolises are car-free (BMVI 2017).

In logistics, too, digitalisation is changing transport chains and the need for and circumstances of travel at various different levels. Intelligent fleet management software is increasingly being used to plan runs, transport chains and transport routes.

Digitised and smart mobility and logistics solutions present both opportunities for more efficient, resource-saving transport and new risks for the environment.

Current opportunities and risks for the environment

Both mobility and Logistics 4.0 have the potential to make transport and traffic more efficient and to reduce the amount of resources they use. At the same time, it is not clear to what extent resources are required for the IT infrastructure and production of the necessary vehicles, and consequently, what environmental impact this will cause.

On the one hand, research (Pratsch 1975) has found evidence of positive effects on the environment from carpooling and vanpooling. As a result of digitalisation, key findings from 1970s and 1980s in the US could be updated and confirmed in a 2017 study by the Massachusetts Institute of Technology (Anderson 2017). On the other hand, the (lack of) regulation to date of digital taxi-like services (ride-hailing and ride-sourcing), such as Uber and Lyft in New York City, has been shown to lead to huge increases in vehicle mileage, energy consumption, emissions and congestion. The use of public transport in the modal split has also declined (Schaller 2018). On this question of regulation in Germany, the findings of the “RechtSInnMobil” project (UBA 2018c), with recommendations for green passenger transport law, are due to be published shortly.

Logistics 4.0 does offer potential for savings, for example fuel savings and therefore a reduction in CO_2 with more efficient route planning or intelligent assistance systems in vehicles. On the other hand, there is the rising demand for ICT, the growing use of broadband networks and a resulting increase in energy and material use.

As far as autonomous driving is concerned, we also need to ask how great an unwanted shift from public transport to private vehicles it might cause, and whether the concept of “robo-taxis” can be applied in public transport. Furthermore, it is as yet unclear what the ecological impact of e-commerce is compared to over-the-counter retailing (both business-to-business and business-to-consumer), and what potential for ecological optimisation exists that could be offered by IT systems in logistics (Logistics 4.0).

A study from 2015 shows a wide range of possible scenarios for opportunities and risks for the environment (Greenblatt et al. 2015). The study’s authors believe that changes in emissions as a result of mobility digitalisation could range from anything from a potential 80 percent reduction in greenhouse gas emissions to a threefold increase. This large divergence is due to a lack of data collection in this area and highlights the need for further research.

Steps for the German Environment Agency and environmental policy

The UBA is therefore planning to conduct further studies in this area in the future. The first “case study on interconnections” will look at logistics, (e-)commerce and production.

Apart from this a basic study entitled “Digitalization of transport – Potentials and Risks for the Environment and Climate” is also currently investigating how big an impact “robo-taxis” could have on local public transport and traffic overall.

An aim in future projects is to show the potential offered by digitalisation for controlling traffic flow in real time by giving priority to vehicles with more passengers, and for monitoring motorised private transport, including stationary vehicles, more effectively. This could, for example, help to reduce the amount of traffic created by drivers looking for parking spaces.

Furthermore, researchers are developing first basics on how the environmental impacts of e-commerce in comparison to that of over-the-counter retailing. The next step will be to develop proposals for a regulatory framework that allows us to leverage the benefits of digitalisation in transport for environmental and climate protection whilst reducing the risks.

4.8 Green energy infrastructure 4.0

Progress of digitalisation and further developments

Withdrawal from nuclear power, broader rollout of renewable energy and climate protection targets: the link between environmental protection and energy has been a subject of discussion for years. The significance of digitalisation, however, has added an important new dimension to the debate, namely smart grids. The focus is on the smart connection of what will in future be increasingly fluctuating output from renewable sources.

The Digital Agenda 2014–2017 (Federal Government 2014) explores the development of smart grids, the modernisation of current distribution networks and the expansion of infrastructure, including energy storage facilities. The corresponding Act on the Digitalisation of the Energy Transition [*Gesetz zur Digitalisierung der Energiewende*] entered into force on 2 September 2016 (Federal Government 2014).

It introduced a new digitised metering and control network – the Smart Meter Gateway – defining minimum technical standards for smart metering systems.

Digitised metering and control are an enabler that forms the basis for more flexibilisation of models, products and markets, for example making it possible to track the generation of renewable electricity. It also allows small, decentralised producers to reduce their billing costs, and energy data to be retrieved in real time with digital technology – and if required processed in more detail using AI or big data. Another important element in the legislative framework will be the IT Security Act (BSIG), which is in future to regulate data transfer and privacy, including in the energy sector.

However, intelligent energy infrastructure connectivity also poses new flexibility and capacity requirements for the electricity grid, not least in the light of the volatile nature of electricity from renewables. Smart networks that communicate with each other can on the one hand make a valuable contribution to more efficient energy use. On the other hand, we need to consider the potential rebound effects of the technology.

Current opportunities and risks for the environment

Here – between energy efficiency and possible rebound effects – is where the opportunities and risks for the environment in Energy 4.0 lie. Smart grids can enable more efficient and economical energy use, in particular with renewable energy (Hu et al. 2014). They could therefore both save energy and, in the long term, reduce energy demand from both private households and industry. Applications for prosumers, for the development of data-driven business models, and for intelligent network and building automation to minimise energy requirements are also conceivable approaches.

Not least in conjunction with electricity from renewable sources, this offers potential for improved environmental protection in energy generation, resource use and energy consumption. Two aspects of particular interest here are efficiency improvements and rebound effects, for example when developments have a broader socioeconomic impact.

Digital technologies can lead to changes in consumer behaviour that in turn feed into wider societal change. For example, it is conceivable that new types of hydrogen storage for electricity from renewable sources and their use with electric cars will change people's chosen mode of transport.

However, although digitalisation has been identified as an important issue for the future of great significance in these areas, the opportunities and risks of digitalisation for climate and environmental protection in the energy sector are still rarely explicitly addressed. Smart grids require the development of new infrastructure for which resources must be used.

Another issue is the energy loss when electricity from renewable sources is transmitted over long distances. Finally, there will be an increase in energy demand for operating and maintaining smart grids. Digitised metering and control is also at risk of hacking (disablers).

Research into possible rebound effects is therefore particularly important in this area if we are better to assess not just the opportunities but also the risks for the environment.

Steps for the German Environment Agency and environmental policy

The UBA is planning to conduct a number of studies to quantify and build up an overall picture of the effects of digitalisation in the energy sector. A particular focus will be on the impact on climate protection. Methods for evaluating opportunities and risks are to be developed and applied to selected practical examples, such as the smart meter rollout.

These use cases will then feed into policy recommendations and evaluations of various digitalisation applications for the energy sector for climate and resource protection.

4.9 Digitalisation and an environmentally friendly chemical industry

Progress of digitalisation and further developments

Digitalisation has made the production of chemicals quicker, more targeted and more efficient. For chemical safety evaluation, digitalisation in the chemical industry means a move from value chains to value networks. This concerns both production processes and markets. The term used by the chemical industry for these various different digitalisation applications is “Chemistry 4.0”.

Many companies in the sector have automated the control of their production facilities using digital processes. The most important driver here is the use of big data in all areas and at all times throughout the process chain, from resource extraction to product design, production, consumption and disposal.

Not only can plants be controlled with smart sensors, but the evaluation of big data enables targeted control. The more data available in real time, the more precisely and therefore potentially more ecologically a product or the chemicals required for it can be produced or used.

New applications and options like these are also opening up new fields of work and business models, as well as new and promising markets for the industry. That is why companies in the chemical and pharmaceutical industry are planning to invest more than one billion euros in digitalisation projects and new digital business models over the coming years (VCI 2017).

Current opportunities and risks for the environment

The digitalisation of the chemical industry is not simply creating new business models, segments and services; it also offers a stronger basis for the substitution of products, chemicals, materials and indeed also energy.

Possibilities include leasing chemicals to conserve resources. Chemical leasing means that manufacturers and importers do not sell the chemicals. Instead, they offer the buyer either the functions performed by the chemical or the chemical itself as a service. After use, the supplier then takes the chemical back and is responsible for environmentally friendly processing or disposal. This can optimise chemical use and improve resource efficiency (OECD 2017). Digitising the chemical industry, which has a huge, cross-cutting role in other sectors, could, moreover, drive a major and decisive improvement in quality.

Such progress can be achieved if key data and information for better chemical safety for people and the environment are provided throughout the process and value chain as well as for the individual product. This means sharing relevant data on the potential greenhouse gas emissions, resource consumption and mobility (potential for long-distance transport) of chemicals, materials and products, and improving the traceability of chemicals that are known to be or are potentially hazardous. In turn, this will increase transparency on resources and process chains used. The ability to trace and examine those resources and process chains for chemicals will also help us to assess the impact of Chemistry 4.0 on both people and the environment.

Improving the data available on the chemical composition of materials such as composites, and improving the traceability of hazardous characteristics for individual substances under certain regulations should also contribute to a circular economy for materials and chemicals. Smart technologies can generate important data, for example for waste systems, chemicals management for industrial chemicals pursuant to the EU Regulation 2006/1907/EC – Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) –, pesticides (plant protection and biocidal products), fertilisers, medicinal products, detergents and cleaning agents and nanomaterials, and can therefore make the use of chemicals and resources safer and more effective. Digital technology can also optimise processes and facilitate documentation, and this can improve the quality of corporate environmental management and environmental reporting. However, alongside this potential, known, existing problems for the environment can worsen and new risks can emerge.

Steps for the German Environment Agency and environmental policy

The challenges for chemical safety posed by the digitalisation of the chemical industry are many and varied, and require a supportive and regulatory political framework for stakeholders and businesses. Finally, but importantly, digitalisation must be taught as part of training and professional development in the chemicals field, and the relevant sustainability aspects explored.

Environmental policy must in this context focus not just on the chemicals themselves, hazardous substance management and general data management, but also on issues such as resource efficiency (materials and energy), secondary raw materials and recycling and traceability, alongside product, application and consumer information.

Action is needed in particular in the light of increased data availability as a result of digital technology. Greater access to data in Chemistry 4.0 could mean greater knowledge on the key areas outlined above thanks to rapid or real-time data input. However, we will need a policy framework that ensures all stakeholders have access to these data.

This quantitative and qualitative improvement in data and information and therefore in knowledge resulting from closer integration of environmental aspects could ultimately have a positive impact on ecology, resource efficiency and sustainability if it led to corresponding changes in practice. These points are already being pursued under REACH and are leading to improvements in consumer information, such as the obligation to provide information, and in the handling and collection of data, with access to important information being provided (data transparency). However, further improvements in chemical safety in the course of digitalisation will require the ongoing connection of information systems on various different aspects of chemicals and their authorisation in different fields of use.

If such opportunities and risks are identified at an early stage and addressed accordingly, digitalisation in the chemical industry could contribute to improvements and greater sustainability in the fields of the environment, health, education and food and thus to overall chemical safety.

1 The term chemicals as used in this text refers primarily to substances and mixtures. Chemicals in other compositions are referred to in this text by the terms materials and products.

4.10 Green agriculture 4.0

Progress of digitalisation and further developments

Robots milk cows, drones measure fields and autonomous vehicles control fertilisation and irrigation: in line with the overall societal trend, all agricultural sectors from crop production to animal farming are also affected by digitalisation. In a survey of German farmers conducted by the industry association Bitkom, two thirds of respondents see digitalisation as an opportunity for the future of their business (Bitkom 2016).

The survey found that almost 40 percent of farmers already use high-tech agricultural machinery and 51 percent use digital automatic feeders. Particularly dynamic development can be seen in the fields of data acquisition, data transport and data processing. A large majority of the farmers are prepared to provide data from their farms as they hope that this will reduce the bureaucratic burden on them.

Precision farming technology in crop production and process automation in animal farming are also already widespread. From a business perspective, digitalisation can offer agriculture greater efficiency and increased productivity.

A position paper dated 13 September 2016 and published by the executive committee of the German Farmers' Association (DBV) states that "the digitalisation of agricultural production processes is a megatrend with great potential for low-resource and climate-friendly agriculture and farming practices that promote and protect animal welfare" [translated from the German original] (DBV 2016).

From a sustainable Agriculture 4.0 perspective, however, the trend presents not just opportunities but also risks for the environment.

Current opportunities and risks for the environment

Potential of Green agriculture 4.0 for environmental protection is usually understood as the prospect of increased efficiency with the more targeted use of resources. Precision farming, for example, allows more targeted sowing, the more precise (and therefore less) use of fertiliser and more efficient irrigation of agricultural land. This can save on fertilisers, pesticides and fuel in order to reduce environmental impact.

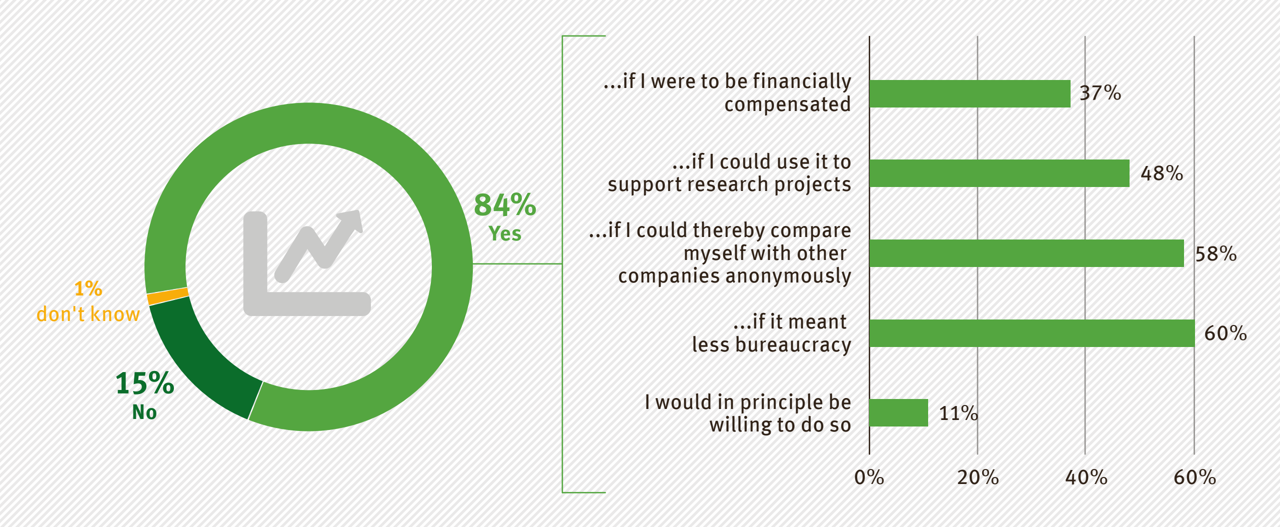
Yet major challenges of digitalisation such as data sovereignty, data protection and negative social implications arise in agriculture just as in other sectors. The agricultural context should therefore always be considered in societal debates and legislative processes.

However, key to reducing the environmental impact of agriculture is the question of the type of agriculture for which digitalisation is used: the one-sided use of digitalisation will simply take the model of agricultural production that is geared exclusively to efficiency and yield, with all its negative consequences for the environment, to a new level. In extreme cases, savings in resources could even lead to an increase in intensive farming (rebound effect). If digitalised management is not specifically intended to reduce the environmental impact of agriculture, biodiversity in the agricultural landscape, for example, will continue to decline in future. Moreover, excessive fertiliser input is often a result not of inaccurate control options but rather of too much manure from intensive livestock farming that is not appropriate for the land or area in question. That is a problem that cannot be solved by digitalisation.

On the other hand, a digital transformation offers great opportunities for the development of an agricultural system that can fulfil key ecological functions as well as providing reliable agricultural production. For example, the availability of data on relief, nutrients, soil condition and climate can make

Figure 6

Interest in data use in the agricultural sector



Source: Bitkom Research

even very complex or small-scale farming systems easier to manage. Crop rotation, undersowing and soil cultivation methods could then be tailored to local conditions. Automation with lightweight robots can help processes to be carried out autonomously and reduce the harmful environmental effects of soil cultivation. Reliable detection of individual plants in a field, for example, could in future allow farmers to protect crops whilst preserving harmless wild herbs and eliminating other, harmful plants. In the animal sector, digitally controlled and improved animal health could reduce the need for medicinal products. This would reduce the release of substances into the environment and potential negative effects.

For this potential to be harnessed, however, the digital transformation must have a stated aim of lessening environmental impact, and that aim must be actively pursued as part of the transformation process. If, for example, herbs that grow in fields are managed digitally and specifically not eliminated in order to preserve biodiversity, the fertilising process would have to be adjusted accordingly. The term “efficiency” would then not only refer to the quantity and carefully timed use of resources such as fertilisers, but also to the additional ecological functions that this type of agriculture would perform.

Steps for the German Environment Agency and environmental policy

Digitalisation can therefore be a tool for improving the environmental impact of agriculture. It could promote necessary structural transformation towards multifunctional, sustainable agriculture adapted to the surrounding ecosystems. However, further development must not be driven solely by a small number of large companies with their own business objectives and potentially conflicting goals.

To prevent market dominance and farmers’ dependence on just a few fertiliser, seed or technology companies, a wide range of players must be actively involved in the development of sensor technology, data transport, data processing and decision-making tools. Training and professional development is also required so that farmers can gain the technical expertise they need to make informed use of digital technology. To secure such developments in the long term, we need clear statutory and private sector regulations on data sovereignty, independent infrastructures for large volumes of data (big data), independent research, consultancy and training, appropriate qualification, open data formats and reliable Internet coverage, including in rural areas.

4.11 Resource-conscious Water Management 4.0

Progress of digitalisation and further developments

"Water Management 4.0" refers to changes in water management resulting from an increasing use of digital technology such as big data, simulation and artificial intelligence. Water management includes complex networks with more than one hundred pumping stations for controlling water and waste water systems in large cities. Digitalisation could have the potential to make a major contribution to overcoming future challenges and shaping sustainable, resource-conscious water management. However, the potential that could ultimately be generated, in particular the benefits for people and the environment, cannot currently be predicted – partly or precisely because of the wide range of possible applications.

Using smart water meters and installing digital infrastructure for pumps and assemblies in waterworks and waste water facilities, for example, could identify potential problems both for the consumer and in the water and waste water networks, and improve energy efficiency in those networks. Demand-based control is one option here.

Comprehensive changes to cross-sectoral data collection and use are also being discussed as part of the digitalisation of water management. Integrated data collection in agriculture, for example, could provide more detailed information on nutrient input to groundwater.

Such multi-dimensional solutions made possible by digitalisation in this area are still in their infancy, and cannot therefore currently be termed as implemented technology or indeed used.

Current opportunities and risks for the environment

Water management today is facing new challenges, not least as a result of climate change, demographic change and the necessary adjustments to methods and technology. Challenges include heavy rainfall events and new substances that need to be removed from waste water. Supply and disposal systems today need to be flexible so that they can adapt to rapidly changing conditions in real time and draw on forecasts. To this end, we need to link waste water disposal, water treatment and precipitation and river basin management infrastructure in one overarching system that integrates and usefully connects all necessary components. In the case of municipal infrastructure, we also need to consider how far "Water Management 4.0" systems could be integrated into or connected to new types of urban structure. Links to other sectors such as agriculture are also of huge significance for water management if digitalisation is to contribute to environmental improvements. Alongside reliable data, IT tools and smart and connected plant control, data and system protection is also essential in this process – not least in the light of increasing system complexity.

Steps for the German Environment Agency and environmental policy

Digitalisation could drive improvements in resource use and green development in waste management. However, the water sector must not exclude related sectors (for example agriculture) or sector coupling. We need to ensure that we build on strong performance in water management to date in adapting to future challenges (for example more heavy rainfall events and demographic change) and that such achievements are rolled out on an even broader and more efficient scale. One objective should be to use water management data to achieve improvements in other areas such as the energy sector or urban spaces in general, or at other levels of government, and potentially also to provide new services. Environmental policy could provide the basis for such improvements by creating a framework for and defining the purposes and targets of cross-sector data use. The UBA could act as a coordinator and mediator between the various stakeholders.

4.12 Digital environmental education and education for sustainable development

Progress of digitalisation and further developments

Traditional environmental education seeks to teach a responsible attitude to the environment and natural resources. "Agenda 21: United Nations Sustainable Development" (UN 1992), published at the Earth Summit in Rio de Janeiro in 1992, defines environmental education as part of the international "Education for Sustainable Development" (ESD) campaign. UNESCO sets out the process required to achieve ESD by 2030 in its latest document on the issue, "Education for Sustainable Development" (UNESCO 2019). Alongside contact with social contexts and a better balance between economic growth and sustainability, digital technology is also to play a part in that process. For example, smart solutions could save energy in the classroom. It is true that digitalisation does not release teachers from their responsibility to shine a spotlight on the fundamental principle itself, namely saving energy. Nonetheless, new technology can be a tool to help achieve that goal, provided there is a critical and sustainability-aware approach to it.

ESD is in part designed to enable people to integrate sustainability into their own way of life, but "competences to create a contribution to sustainability" [*Gestaltungskompetenzen*] remain at the heart of the ESD concept.

Environmental education and education for sustainable development are rooted in the traditional education environment, and take place in "project weeks" and at informal and out-of-school places of education.

In its report "World in Transition – A Social Contract for Sustainability" (WBGU 2011), the German Advisory Council on Global Change also emphasises the importance of transformative education and education about transformation in research and educational institutions. This means not only teaching a focus on sustainability transformations, but also integrating climate-compatible digital technology into research, development, application and analysis and their spread in order to become transformative. The long-term global and social impact of digital services and how climate-friendly they are need to be examined, and where necessary new, sustainable digital solutions need to be developed.

This is particularly important as education is currently undergoing major changes as a result of digitalisation. Teaching and learning are increasingly happening virtually: e-readings, Massive Open Online Courses (MOOC), webinars, virtual academies, Moodle courses, learning apps and SchulCloud (HPI, n. d.) are just some examples of digital learning environments. Research is also increasingly being conducted virtually, for example with search engines, Internet databases and online libraries. All this offers many areas of application for digital environmental education and education for sustainable development.

Digital services could be used in a range of institutions such as nurseries, schools and universities and in leisure facilities. The initiative "*Finde Vielfalt – Biodiversität mobil entdecken*" (https://biodivlb.jimdo.com/) run by Ludwigsburg University of Education, the University of Bamberg and the German Youth Hostel Association teaches about biodiversity in games on smartphones and tablets for children and young people in youth hostels. The online game "Pimp your Landscape" explores sustainable land development in a fun way (https://www.letsmap.de/letsmap/index.php).

In adult education and professional development, too, digitalisation is opening up new opportunities for digital environmental education and education for sustainable development with online courses and digital educational programmes.

Current opportunities and risks for the environment

This offers new potential but also poses risks for the environment: whilst digital education opportunities can make environmental education available to more people and in the best-case scenario thus increase users' knowledge, digital services also require more resources. For example, institutions need new or more ICT equipment; the Digital Pact (BMBF 2019) is designed to provide them with the necessary support.

At the same time, access to the broadband network also needs to be improved and ensured. These developments involve a greater use of materials and energy and can therefore have a negative impact on the environment. On the other hand, there could be opportunities for saving materials, as digital formats can replace physical material or render it superfluous, saving on resources such as wood, water and energy.

To date, however, there has been little research into the links between digitalisation, digital environmental education and their effect on the environment. It is also important to evaluate the educational aspects of digital measures and measures' impact on personality development.

Steps for the German Environment Agency and environmental policy

Research in the coming years should therefore focus initially on precisely those two areas: an ecological "profit and loss" from the digitalisation of education, and the necessary balance between traditional education and new, digital and virtual authorities that may not have had any educational training. It would make sense here to take an interdisciplinary approach that draws on creativity, neurobiological and brain research. One question to be explored is whether the "shaping" and ambiguity training required for transformation and coping with uncertainties can be achieved through binary programming, or whether this approach would instead teach black and white thinking. A number of studies have also indicated that learning is an active brain process in which the learner generates meaning and develops their own systems of evaluation (Gebauer et al. 2005). Only then do social skills and a desire for and expertise in experimentation and improvisation also emerge and develop.

Another point is that, although the possible benefits of digital media and applications in the context of education should be recognised, digitalisation must not be reduced to technical equipment and the ability to use it; the issue of societal change through digitalisation must also be discussed, explored and developed. We therefore need a critical approach to the digital transformation of environmental education in all its facets and with all its grey areas.

This means, for example, considering aspects such as ecodesign, obsolescence and sufficiency as part of digital education on resource conservation, including those aspects in lessons, and discussing them with learners. Another challenge is to shape the digital transformation to reflect and fulfil the UN Sustainable Development Goals (UNESCO 2019). How can we ensure that digital environmental educational services do not just explore environmental protection, but are also equally accessible to everyone (leave no-one behind) and are themselves sustainable?

Whilst it is important to make use of the opportunities that digitalisation offers for environmental education at school (technological resources permitting), this cannot and should not be done without improving pupils' digital skills: pupils will only be able to assess technology's sustainability if they understand its underlying mechanisms. Teachers' digital skills also need to be strengthened, and they need to engage in a discussion and evaluation of their suitability for ESD. Digital environmental education and ESD therefore still require wide-ranging and in-depth reflection if technological potential is to be reconciled with professional educational support for learners.

5

Digitalisation in environmental policy and public administration

Digitalisation in environmental policy and public administration

Digitalisation does not only present opportunities and risks for environmental protection and resource conservation in the environmental policy areas set out in section 4. A holistic approach to the issue makes the environmental policy and its institutions themselves a target for environmental policy related to digitalisation, as digitalisation also changes the way in which environmental policy and administration work. We must ask how effectively environmental policy and administration could work in a digital or digitised world.

In this area, we need to harness the opportunities offered by digitalisation both in own work processes and in communication with the public. Digitalisation opens up new possibilities for constant, continuous and reliable data acquisition, analysis and evaluation. At the same time, digital technologies such as VR and AR could not only make environmental information publicly accessible but also enable citizens to experience it in a new way, promoting dialogue and strengthening environmental awareness.

However: digitalisation cannot be a means to an end. In the work of the UBA, it must always be pursued in accordance with the principle of sustainability. This will only be possible if environmental protection is considered from the outset in all processes. To this end, the UBA must critically examine and sustainably shape its own approaches and methods from data collection to evaluation and external communications, with a view to environmental protection, data protection and inclusive citizen participation. This means first and foremost environmental monitoring, environmental information and e-government. Section 4.12 sets out how environmental education and education for sustainable development can make a difference in an increasingly digitised and digital world.

5.1 Digitalisation and environmental monitoring and information

Progress of digitalisation and further developments

Environmental monitoring and environmental information traditionally require the collection, sorting and analysis of a large quantity of data. As digitalisation progresses, this process is increasingly being done using digital technology. There is a legal framework for the digitalisation of environmental monitoring and environmental information. This includes the Environmental Information Act (section 1 par. 1 UIG), the Freedom of Information Act (section 11 par. 3 IFG), the E-Government Act in conjunction with the Open Data Act (section 12a EGovG) and the Geodata Access Act (section 1 GeoZG), which implements the INSPIRE Directive (EU Directive 2007/2/EC). Relevant EU directives and the national legislation implementing them also apply. One focus of this national and European legislative framework is the establishment of a Europe-wide infrastructure for spatial information, with Sensor Observation Services (SOS) providing almost real-time online data from measurement networks – for example from Germany's national and federal state air monitoring networks.

The purpose of the spatial data infrastructure is to standardise and simplify the provision and use of monitoring data. In future, satellite remote sensing will play an even greater role in the digitalisation of environmental monitoring. For example, the Sentinel family of satellites from the EU's Copernicus programme and the services linked to them already provide important information.

They help to check compliance with directives in fields such as agriculture. Digitalisation in environmental monitoring, for example with the INSPIRE Directive, has led to more comparable data across Europe. Increasingly, data are no longer actively supplied by Member States, but instead "collected" by the European Commission or the European Environment Agency. Satellite remote sensing has large regional coverage and a high repetition rate, which means that additional data harmonisation is no longer necessary.

Current opportunities and risks for the environment

Although environmental monitoring and environmental information have always been based on data i.e. digital information, digitalisation offers clear opportunities for further developments in environmental monitoring. Ongoing sensor developments in remote sensing, small satellites, drones with microsensors, wireless and mobile sensor networks and systems, citizen science and last but not least better (automated) data analysis, evaluation and presentation options are enabling the global and continuous recording of environmental parameters. The problem with small non-controlled satellites is that they are actually designed to remain in orbit as "orbital debris", and this endangers other missions.

Digitalisation has the potential to increase the impact and reach of environmental information and knowledge and better to tailor information services to specific target groups. Environmental information could be integrated further into the consumption of information through social networks or smart (home) assistants. New Web tools could in future allow environmental information to be presented in a more interactive, narrative, thematically integrated and customised way. Technical innovations such as AR or VR (for example the digital display of information using VR glasses) could allow people to experience environmental information at a completely new level.

However, certain groups of users might find it difficult to cope with the large number of potential new services and transmission channels. Moreover, information could be perceived as manipulative if it were integrated more into users' everyday lives. Another challenge is growing competition from private providers of (environmental) information.

Steps for the German Environment Agency and environmental policy

The digitalisation of environmental monitoring is opening up a number of new areas that need to be addressed by the UBA. These include, firstly, collecting better-quality environmental data in a more targeted manner with the help of digital technology. Further developments in satellite sensors will play a key role here. Higher resolutions and additional spectral channels in conjunction with the relevant in-situ data will contribute to further improvements in environmental monitoring.

Secondly, the UBA website already provides a wide range of environmental information in digital brochures and online databases with information on all environmental issues. For example, the website has an overview of all environmental indicators in Germany, and details of current air pollutant concentrations. An air quality app is also planned for the summer of 2019. The "Tatenbank" database contains examples of best practice for adapting to climate change as achieved in climate protection projects from across Germany. The Pollutant Release and Transfer Register and its website www.thru.de bring together information on pollutant release, waste disposal and emissions from diffuse sources.

We now need to make existing information available to the public and political decision-makers more rapidly and more efficiently. An important step in this direction is the Europe-wide standardisation of environmental monitoring on the basis of cross-border projects, for example the development of a common infrastructure for spatial information for Europe as part of implementation of the INSPIRE Directive (EU Directive 2007/2/EC). INSPIRE is aimed at standardising data collection and analysis methods across Europe.

To date, different methodologies have been used in different countries. In emergencies, however, it is vital to be able to share relevant environmental information as quickly as possible, even across national borders. Following the volcanic eruption in Iceland in 2010, for example, many countries needed weather and air quality data. Without uniform standards, it can take a long time for decision-makers to decode all the necessary data. Uniform EU standards for environmental monitoring are needed to allow a more rapid response in such situations. The UBA is involved in this project.

Thirdly, digitalisation offers a better basis for targeted monitoring. At a national level, the UBA's Geographical Information System (https://gis.uba.de/website/umweltzonen/index.html) can be seen as a contribution to the provision of monitoring results in the form of map services and metadata through geoportal.de, Germany's "geoportal". The UBA is also making an international contribution by providing data through the GEOSS portal (Global Earth Observation System of Systems). The huge amounts of data to be processed – in the EU's Earth Observation Programme Copernicus, for example, estimated satellite data volume is currently 10 petabytes per year (DLR, n. d.) – are driving the use of cloud solutions. Cloud solutions can have a positive effect on the carbon footprint, for example if the data centres used follow a green IT approach (see "Green and low-resource information and communications technology"). Challenges here include ensuring data quality, managing the volume of data, and developing and operating efficient data centres, algorithms and software and hardware products.

Fourthly, digitalisation can make it possible to provide and disseminate data in a more targeted way, and to add new dimensions to dialogue with various groups in society. The UBA is gradually to expand the information it offers, adding new functionalities and services. A focus on user expectations and user experience in research projects will ensure the greatest possible reach and best possible transfer of information for different user groups. The potential of virtual reality and augmented reality for the communication of environmental information is to be analysed in the medium term through research projects (with specific examples for practice). The UBA already uses online communication via its website and social media platforms to communicate with the public, scientists, decision-makers and other target groups, and to tell them about its work and the state of the environment.

Fifthly, by disseminating accurate and reliable data and analyses through the various media channels, the UBA can counteract the risk of manipulation and misinformation in public debates and discourses caused, for example, by social bots and incomplete or inaccurate information in social media. The sixth point is that easily accessible and comparable data facilitate environmental law enforcement by reducing the time and effort involved in data collection and by simplifying the interpretation of the data. What is more, they make it easier for the public to participate in decisions that affect the environment.

5.2 Electronic administration and citizen participation

Progress of digitalisation and further developments

Digitalisation is shaping not just the economy and civil society, but increasingly also public administration and its interaction with private stakeholders. This is known as e-government. The concept relates firstly to pure technical solutions – such as websites, interfaces to data and documents, e-mail contact, social media, electronic transaction processing, etc. However, the overarching objective of e-government is much broader.

The aim is to establish coherent digital processes to carry out public-sector tasks more quickly, more efficiently, more securely and more economically. Processes are to be accelerated, communication simplified and the quality and efficiency of public administration thus improved. E-government opens up new ways to contact the public authorities for both individual citizens and businesses. Alongside improvements in efficiency, e-government therefore also creates new opportunities for political participation (e-democracy) and increased transparency in democratic decision-making processes and the actions of public authorities (e-governance). E-government is a central component of the Federal Government's digitalisation strategy.

Since 2013, the "E-Government Act" (*Bundestag Drucksache* 17/11473) or Act to promote electronic government and amending other regulations [*Gesetz zur Förderung der elektronischen Verwaltung sowie zur Änderung weiterer Vorschriften*] together with other national, state and local legislation has formed the basis for facilitating electronic communication with the authorities and enabling simpler, more user-friendly and more efficient electronic government services. The key points of the Act include:

- **Government obligation to provide an electronic channel of communication, including electronic invoicing;**
- **Fulfilment of publication obligations with electronic official gazettes or official journals;**
- **Duty to document and analyse processes;**
- **Rules on the provision of machine-readable data by the authorities (open data).**

Current opportunities and challenges for the environment

The digital modernisation of administration and government has considerable potential for reducing environmental impact. According to the Federal Government, for example, simply switching from paper to electronic invoices could reduce its CO_2 emissions by around 50 %, which would mean a saving of around 6000 metric tonnes of CO_2 each year just for the Federal Government (*Bundestag Drucksache* 17/11473).

Further green potential lies in bringing together central government services, optimising administrative procedures and improving cooperation between authorities.

Examples:

- Digitalisation of central registers and processes for the enforcement of environmental laws and environmental reporting obligations (for example, the development of the process data accelerator "Prozessdatenbeschleuniger P23R");
- Provision of digital information services and platforms for citizens, the research and scientific community, and business, including services for promoting and connecting citizen science projects;
- The establishment of opportunities for greater participation and (political) involvement in the legislative process.

Taking into account existing constitutional principles and European and national legislation, we need to create solutions within the overall architecture of e-government that at least reduce the previous dual structure of analogue and digital services, and that ensure high standards in terms of user-friendliness, data sovereignty and security (Maas 2018).

Steps for the German Environment Agency and environmental policy

Digitalisation can facilitate public participation. Digital services can give the public easier access to the information required to assess environmental decisions, for example online publication pursuant to the Environmental Impact Assessment Act [*Umweltverträglichkeitsprüfungsgesetz*].

For example, the UBA offers applicants and those subject to statutory requirements Web-based solutions for fulfilling their obligations (e. g. for the DEHSt [German Emissions Trading Authority], enforcement of BattG [Battery Act] and ElektroG [Electrical and Electronic Equipment Act], and the HKNR [Register of guarantees of origin]). The UBA also promotes public participation in federal authority approval procedures that are subject to environmental impact assessments by operating the "UVP-Portal des Bundes" (www.uvp-portal.de) EIA portal, and shall continue to develop the portal together with the federal regulatory authorities. Online participation options can facilitate the submission of comments and feedback.

Digitalisation can also have a positive impact at a local level in the implementation of environmental protection and planning measures, for example in municipal land management and the simulation of the effects of local climate change adaptation. Over the next few years, the UBA will therefore continue to expand development of digital services for local authorities. These include the website "www.aktion-fläche.de", urban dashboards and integrated and interdepartmental data-driven control and evaluation models for climate adaptation activities.

One special area of digital services is the planning and development of mobile applications (apps). Additional options for members of the public, end users and consumers are conceivable alongside the existing hazardous substance app, which is aimed primarily at professional users. An app with climate data to raise awareness of climate change issues is also a possibility. Such an app could link in individual behaviour and calculate the user's personal resource footprint, and recommend individual action.

In the spring of 2019, the UBA and BMU organised a "hackathon" for environmentally-minded young people. This signalled a new and, in the context of federal policy, innovative step aimed at driving forward the development of environmentally friendly applications, in particular mobile apps. There are plans to repeat the event.

Finally, the German Environment Agency will in future intensify its work in detecting, monitoring, evaluating and shaping the indirect effects of digitalisation and its regulatory framework on environmental protection and environmental policy, not least in the context of e-government. Such work will include a more in-depth examination of the links between environmental protection and (inadequate) data protection, and the transparent provision of legally sound and user-friendly licensing models as the basis for the automated retrieval of administrative data.

6

Outlook

Outlook

Digitalisation brings both opportunities and risks for environmental protection and environmental policy. As the societal debate on digitalisation has so far focused primarily on economic and legal aspects, the UBA is seeking to help raise public awareness of the impact of digitalisation on the environment.

Our approach is to pinpoint trends in and options offered by digitalisation and to identify the opportunities and risks in each area. Since digitalisation is bringing certain fields closer together (for example in coupled infrastructure) and the ultimate effects on the environment are often unclear (for example energy savings with smart meters versus raw material and energy consumption in the production of control technology), the combined impact of multiple trends and how those trends interact must also be considered. On this basis, digitalisation needs to be shaped for the long term through environmental policy, and its benefits for environmental protection need to be harnessed.

Digitalisation is not a new concern for the UBA; it is an issue that is already an integral aspect of much of our ongoing work. In other words, the UBA always considers digital aspects as part of its research, scientific policy advice, in the application of legislation, as part of information and data services, and in other activities.

Greater expansion in capacity and expertise in this area is therefore also important. The UBA sees digital literacy as a key element that will be relevant to all UBA staff in the future.

In the light of the diversity, complexity and dynamic nature of digitalisation, we must intensify our exchange with business, the scientific community and civil society so that better use can be made of the opportunities of digitalisation for sustainable development, and the negative effects of digitalisation on the environment can be avoided.

7

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