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Environmental Technology Atlas for Germany

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Preface

Dear Reader,

Environmental technology and resource efficiency is driving sustainable development around the globe. For Germany's technological and industrial base, too, it is impossible to overstate the importance of green technologies. In 2016, these technologies accounted for 15 percent of the country's gross domestic product (GDP), a figure forecast to rise to 19 percent by 2025. 1.5 million people already earn their living in this discipline – another number that is increasing. Management consultancy Roland Berger predicts that, between now and 2025, the green technology industry will grow by an average of 6.9 percent per annum.

Environmental technologies are modernizing our economy. They are giving us more sustainable products. The German green tech market is expanding at a rate of 8.8 percent per year – considerably faster than the international market. This underlines the extent to which Germany's economy and society is already on the right track.

Environmental technologies also provide answers to the question of how we can meet the basic needs of a growing population without further destroying the ecological foundations for life on Earth.

At the same time, digitalization is bringing radical change to green technology. In many cases it is a fundamental prerequisite, putting in place the technological conditions for environmental protection measures such as the optimized use of renewable energy. Compared to non-automated processes, smart connectivity helps us achieve significantly greater savings on resource consumption. Flexible production systems roll out customized products at the cost of volume-manufactured goods.

In this context, it makes more sense than ever to bring industrial production back onshore to Germany. Some companies are already showing the way forward. Yet we are fully aware that digitalization alone is no guarantee of sustainability: It can mean added resource consumption and the transportation of more goods. It is therefore our responsibility to identify and avoid associated burdens on the environment as quickly as possible.
If green tech firms are to benefit from the digital transformation, they must learn to play by the rules of this new game. Accordingly, this new issue of the GreenTech Atlas for the first time homes in on the role played by digitalization in the small and medium-sized enterprise (SME) landscape that shapes much of Germany's green tech industry. Specifically, it examines how well prepared Germany's environmental technology and resource efficiency companies are for the digital transformation. Looking at the findings, it is fair to say that action is needed in both the political and economic arenas.

We must also prepare ourselves for fiercer global competition. The attractiveness of this market is an open secret. In emerging countries in particular, major global players are adopting clearly defined strategic positions.

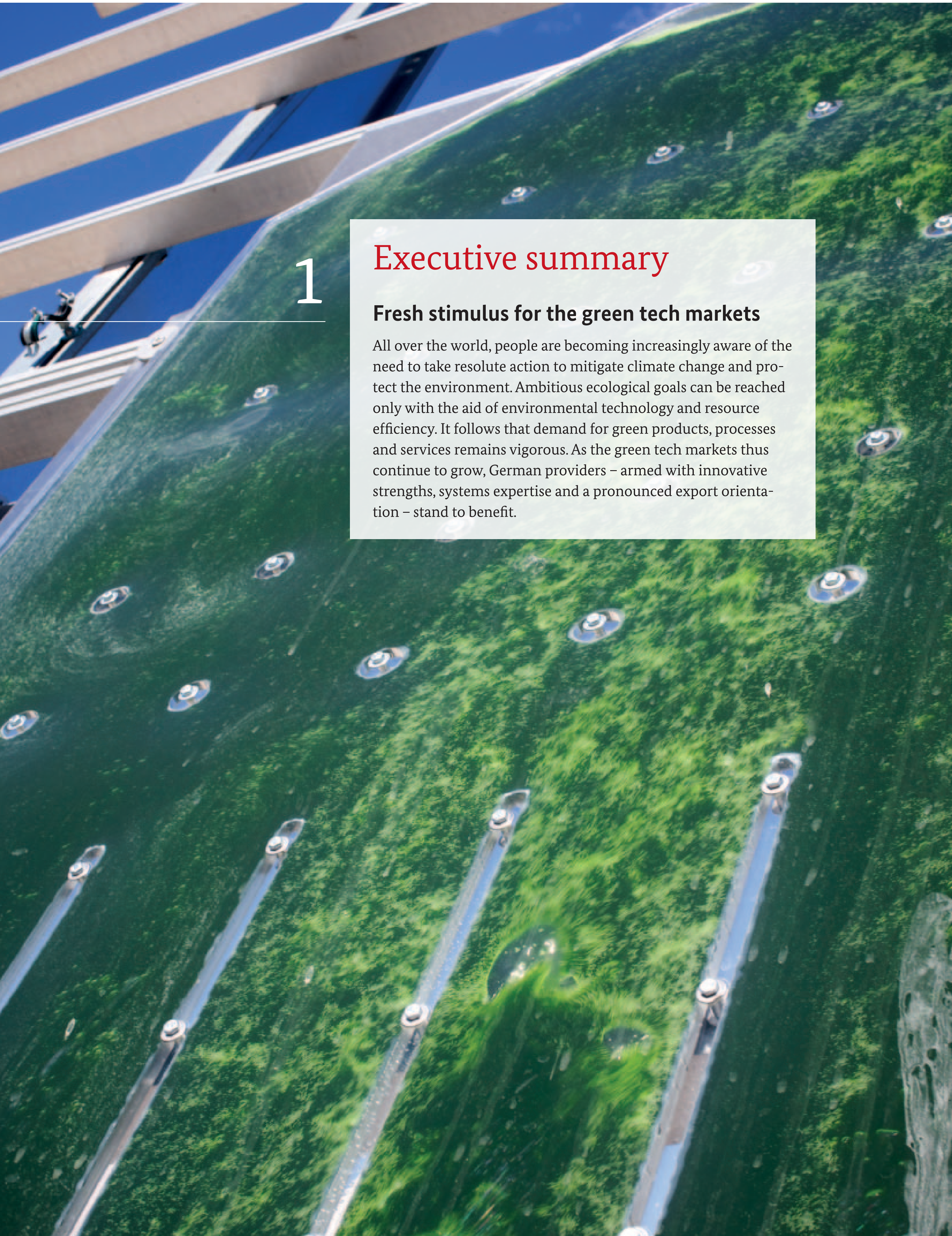
German providers are ready for the onslaught, at least in principle. They possess a wealth of industry expertise. Resting on our laurels is not an option, however.

Both the corporate community and the political echelons must give Germany's green tech industry a sharper competitive edge. Germany must further advance its areas of specialization. Ultimately, a stronger emphasis on the social and ecological aspects of sustainability will determine the extent to which German companies become better able to compete.

A modern industrial society is the backbone of our economy. The GreenTech Atlas demonstrates that "green markets" harbor vast potential for growth. This is where the jobs of tomorrow are springing up.

In other words, sustainability gives us an opportunity to tread new paths and create new value. To realize this potential, however, we must all continue to pull together. The GreenTech Atlas 2018 is a powerful source of motivation!

Svenja Schulze,
Federal Minister for the Environment,
Nature Conservation and Nuclear Safety



1 Executive summary

Fresh stimulus for the green tech markets

All over the world, people are becoming increasingly aware of the need to take resolute action to mitigate climate change and protect the environment. Ambitious ecological goals can be reached only with the aid of environmental technology and resource efficiency. It follows that demand for green products, processes and services remains vigorous. As the green tech markets thus continue to grow, German providers – armed with innovative strengths, systems expertise and a pronounced export orientation – stand to benefit.

Sustainable economic growth – It's time to take action!

Around the world, mitigating climate change and protecting the environment are being accepted as challenges that face us all. In December 2015, representatives of 195 countries and the European Union put their names to the **Paris Agreement**, whose core provisions are these:

- Keep global warming to well below two degrees Celsius while striving to limit the temperature increase to 1.5 degrees Celsius.
- Cut net greenhouse gas emissions to zero by the middle of the 21st century.
- Provide financial support to help emerging countries take steps to tackle climate change and adapt to its consequences.
- Resolve and implement national plans to curb climate change.

Trade associations, civil society stakeholders and local, regional and national governments are swelling the ranks of the alliance against climate change. The determination to work together to combat climate change is growing all the time – as forcefully attested by the 23rd Conference of the Parties in Bonn in November 2017.

We know that there is a close correlation between safeguarding our climate, fostering sustainability and ensuring a livable environment. For this reason, protecting the environment, mitigating climate change and conserving natural resources is an integral component of the United Nations' (UN) 2030 Agenda for Sustainable Development, which was ratified in September 2015 at a UN Sustainable Development Summit for heads of state and government in New York. Given that it addresses every aspect of the realities people face every day, the 2030 Agenda is seen to embody a new quality of international sustainability policy.

Seventeen Sustainable Development Goals (SDGs) form the **core of the 2030 Agenda**. These goals embrace all three dimensions of sustainability – the social, environmental and economic dimensions – and are to be reached by 2030. It describes sustainability as an opportunity to tread new paths in the creation of value. For the German economy, this means that, in the years ahead, green technology must be developed into the cornerstone of national value creation.

Treading new paths in value creation – Continuing growth in the international green tech markets

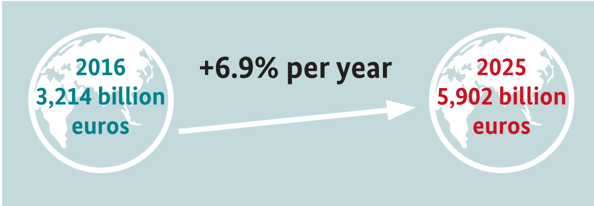
Innovation in environmental technology is an essential element in mastering ecological challenges. There is no question: If we are to achieve the goals laid out in the Paris Agreement and the 2030 Agenda, we need environmental technology and resource efficiency products, processes and services. Very obviously, there is a close correlation between regulatory and environmental policy conditions on the one hand and innovation and the emergence of new markets on the other hand.

This mechanism is keeping demand for green products, processes and services on a high level. The numbers bear impressive witness to this assertion: The **global market volume for environmental technology and resource efficiency** exceeded the 3 trillion euros mark in 2016, ending the year at 3,214 billion euros.

This figure is the sum total of the market volumes for the six green tech lead markets:

- Energy efficiency: 837 billion euros
- Sustainable water management: 667 billion euros
- Environmentally friendly power generation, storage and distribution: 667 billion euros
- Material efficiency: 521 billion euros
- Sustainable mobility: 421 billion euros
- Waste management and recycling: 110 billion euros

Around the globe, the green tech industry is continuing to grow. **By 2025, the global volume of the six green tech lead markets** will probably have reached **5,902 billion euros**. This figure is based on forecasts that the cross-sector industry for green technology will grow at an average annual rate of 6.9 percent between 2016 and 2025.



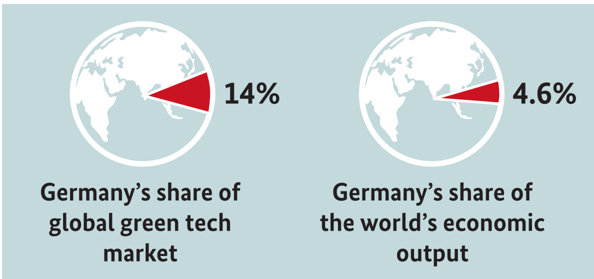
Naturally, the individual lead markets are not all expanding at the same speed. Double-digit average annual growth of 10.2 percent is the impressive figure for the lead market for sustainable mobility. Rapid expansion is also being achieved in material efficiency (8.1 percent) and waste management and recycling (7.4 percent).

Top ten technology lines worldwide

The top ten technology lines were identified based on two criteria: a large share of the total global market volume for environmental technology and resource efficiency, and a relatively high average annual growth rate. These **"top ten" technology lines together add up to a market volume of 1,284 billion euros** – nearly 40 percent of the world's total green tech market volume. It is immediately striking that five of the top ten technology lines – water distribution, water treatment, wastewater treatment, water production, and wastewater collection and transportation – all belong to the lead market for sustainable water management. This weighting bears clear testimony to the increasing importance of supplying water to a growing world population and dealing with an ever more acute water crisis.

Continued robust demand – International successes for "green tech made in Germany"

In recent years, German providers have been able to benefit from rising global demand for green products, processes and services. Especially in the EU member states, where demand is strong, but also in the BRICS countries[1], Germany already enjoys a superior market position with technologies to mitigate climate change. In 2016, **German companies accounted for a 14 percent share of the global market for environmental technology and resource efficiency**. The fact that Germany produces 4.6 percent of the world's economic output puts this figure in perspective and evidences the tremendous significance of German-made environmental technology and resource efficiency on international markets.



1 The abbreviation BRICS stands for Brazil, Russia, India, China and South Africa.

Robust demand for green tech in Germany reflects how well established environmental technology and resource efficiency is on the domestic market

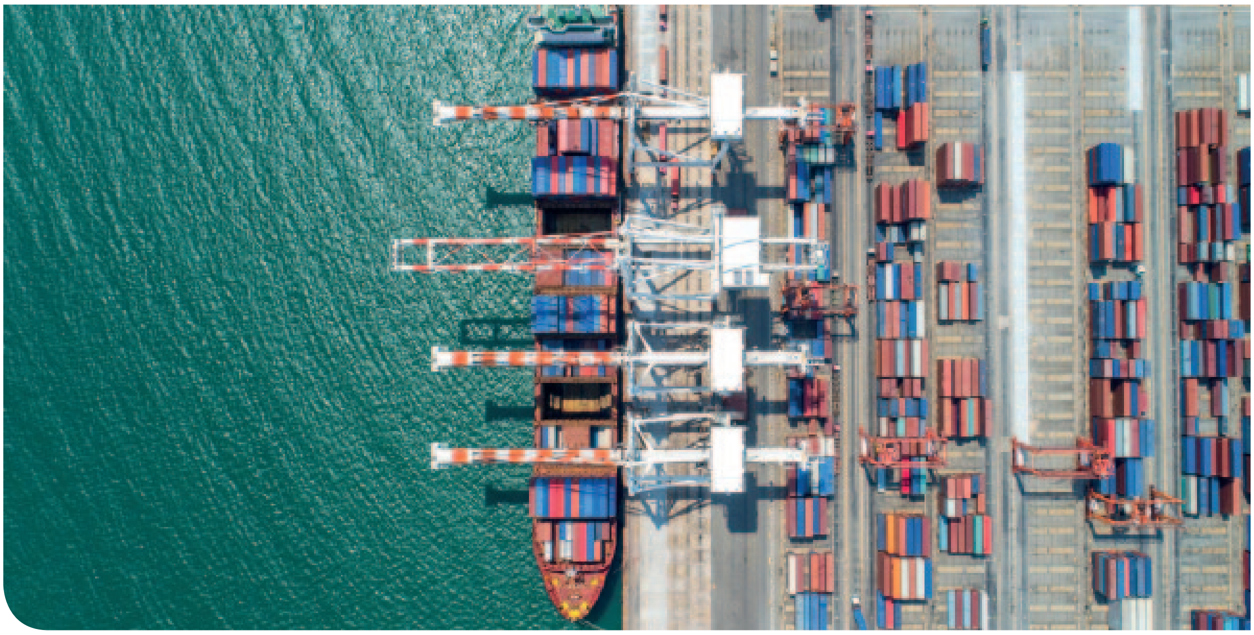
In Germany, the market volume for environmental technology and resource efficiency stood at 347 billion euros in 2016. This figure breaks down as follows across the six green tech lead markets:

- Energy efficiency: 83 billion euros
- Environmentally friendly power generation, storage and distribution: 79 billion euros
- Sustainable mobility: 74 billion euros
- Material efficiency: 63 billion euros
- Sustainable water management: 28 billion euros
- Waste management and recycling: 20 billion euros

While dynamic development is thus expected on the international green tech markets, the cross-sector industry for environmental technology and resource efficiency will also expand in Germany itself. Between 2016 and 2025, the total volume of the country's own green tech lead markets is projected to jump from 347 billion euros to 738 billion euros. Throughout this period, the German green tech industry is expected to grow at an average annual rate of 8.8 percent.

Demand for green technologies is therefore increasing faster in Germany than on the global markets. In the years ahead, strict environmental standards, the energy transition and companies' awareness of energy and material efficiency will fuel further growth in demand for green products, processes and services. At the same time, **demand on the domestic market also creates opportunities for green tech companies based in Germany**. Enjoying far closer proximity to their customers, they can collaborate with users to tailor the development of new technologies to individual needs. Cooperation on their home market is also conducive to systemic approaches within the green tech industry. Thanks to their **expertise in system solutions and their wealth of technological knowledge**, German-based environmental technology providers in particular can experience international success while also tapping large shares of the domestic market volume.

A closer look at the individual technology lines in the various lead markets reveals rapid expansion in sustainable mobility. When a **list of the top ten technology lines** was compiled based on "average annual change between 2016 and 2025", it was conspicuous that five out of the ten fastest-growing technology lines all belong to the **lead market for sustainable mobility**. Driving this growth is the **transition to environmentally compatible, low-carbon mobility in the transport sector**.



Different angles on the same growth industry: Green tech companies in Germany – A strong SME segment

A growing market volume is not the only indicator of green technology's increasing importance in Germany. Another is the contribution made by this cross-sector industry to economic output: Environmental technology and resource efficiency has increased its share of German gross domestic product (GDP) continually since 2007, reaching 15 percent in 2016. The expectation is that, by 2025, green technology will make up 19 percent of Germany's GDP.

As well as sketching the macroeconomic situation, the publications in the green tech series also paint a detailed picture of the supply side of the environmental technology and resource efficiency industry in Germany. That includes both structural data and analysis of moods and trends. This portrait of the industry is based essentially on analysis of a web-based company survey conducted from July through November 2016 on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Our analysis confirmed the industry's existing structural parameters: **Medium-sized companies play a powerful, formative role in the environmental technology and resource efficiency sector**. Roughly 90 percent of the country's green tech players post annual revenue of under 50 million euros. A detailed breakdown of sales revenue nevertheless shows that, among German providers of green products, processes and services, firms with annual revenues of under 1 million euros are also well represented, accounting for 43 percent of all players in the industry. The average green tech company in this country reports annual revenue of 25 million euros. Approximately three quarters of German environmental technology and resource efficiency companies employ fewer than 50 people.

Across the individual lead markets in the German environmental technology and resource efficiency industry, the export rate – the percentage of sales generated outside Germany – ranges from 29 to 48 percent. The share of sales realized abroad is especially high in the lead markets for sustainable mobility (48 percent) and material efficiency (45 percent).

The mood among Germany's green tech providers is mostly positive. 47 percent of the respondents to our survey rate their current business situation as "good", while 45 percent see it as "satisfactory". Looking ahead, the German green tech players are cautiously optimistic. One third believe that their business situation will improve through 2021. 60 percent expect it to remain unchanged, and only 6 percent expect their business situation to deteriorate.

Green tech players' expectations regarding the trends in sales and employment likewise provide an insight into the mood in the environmental technology and resource efficiency industry. Between now and 2021, our survey participants anticipate average annual sales growth of 9.8 percent. The fastest growth is expected by companies that focus on the lead market for sustainable mobility, who expect to see sales increase by an annual average of 14.5 percent.

In the same period, respondents expect the **headcount in the environmental technology and resource efficiency industry to grow by 6.7 percent per annum**. As with sales projections, companies with a focus on the lead market for sustainable mobility again have the highest expectations in the green tech industry with regard to the employment trend. They expect the workforce to increase by an annual average of 20 percent. **Around 1.5 million people in Germany worked at companies in the six green tech lead markets in 2016**.

Fresh potential – Digitalization in environmental technology and resource efficiency

The **dynamic development precipitated by the digital transformation** is bringing radical change to the economy and market conditions, to society and the way we live our lives. In the cross-sector **green tech industry** too, digitalization will lead to **far-reaching changes that present both opportunities and risks**.

Four keys to digital transformation – digital data, automation, connectivity and digital customer interfaces – are influencing the structure of the green tech market. The main changes that affect the providers of green products, processes and services can be condensed into five hypotheses:

- New, disruptive business models are replacing old business models
- Traditional corporate structures are becoming more flexible
- Virtual platforms are forcing changes in market design
- New competitors are penetrating links in the value chain
- Network effects are becoming established as a new competitive advantage

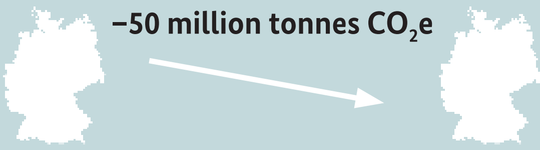
Digitalization can create positive stimulus for the ongoing development of environmental technology and resource efficiency by supporting and advancing systemic approaches. Individual components are linked together to form interlocking systems and thus create end-to-end solutions. This systemic approach is playing an increasingly important role in the context of competitiveness and innovation, because the advanced stage of development in the green tech lead markets is making it ever more difficult to improve individual green products, processes and services.

Digitalization is increasingly evolving into an enabler of system formation, as the four keys to digitalization (digital data, automation, digital customer interfaces and connectivity) lay the foundation for innovative digital systems. At the same time, new products and services are being developed alongside innovative ways to use existing components. Examples of digital systems include connected energy, building information networks, Industry 4.0, urban connected mobility and smart grids.

Environmental technology and resource efficiency is already a fast-growing market. Digitalization can further accelerate expansion in this sector: The synergies and system effects arising from the expansion of digital systems will probably lead to stronger demand for green tech products, methods and services.

Calculations based on the Roland Berger market model **forecast that digitalization will add more than 20 billion euros to Germany's green tech industry in 2025**. The individual lead markets will, however, make varied contributions to this potential: The strongest effect is projected to come in the lead market for energy efficiency, with digitalization adding 7.2 billion euros to the market volume. The least digitalization-driven growth will be in sustainable water management (1 billion euros) and in the lead markets for material efficiency (2 billion euros) and waste management and recycling (2 billion euros).

Environmental technology and resource efficiency inherently contain significant potential to ease the burden on the environment and protect environmental goods. Environmental relief potential is understood to mean the extent to which using a product, process or service eases the burden of pollution on the environment. Growth in the green tech market therefore also leads to positive ecological effects that are amplified by digitalization.



Effect of digitalization in 2025:
5% CO_2e savings compared to CO_2 emissions in 2014

Across the six lead markets, digitalization is expected to yield environmental relief potential of 50 million tonnes of CO_2e[2] in 2025. That is equivalent to a 5 percent reduction in Germany's total CO_2e emissions compared to 2014[3] – from the effects of digitalization alone.

Digital readiness – The challenges facing German green tech providers

Digitalization gives German environmental technology and resource efficiency companies the chance to improve their **competitive position** by injecting innovation into their products and internal processes. Conversely, companies that ignore the megatrend toward digitalization run the risk of losing market share. What is known as **"digital readiness" is key in determining who the winners and losers will be**: To what extent are companies ready for the digital transformation?

The point of departure for companies in the green tech lead markets is determined on the basis of four criteria: start-up activity, the use of digital technologies, the existence of digital systems and the pace of innovation. Based on a qualitative assessment of these four criteria, the degree of digital readiness in each lead market was calculated on a scale from 0 to 100 percent.

Of all the green tech lead markets, energy efficiency leads in terms of digital readiness with the highest score of 80 percent. A large number of start-ups and a broad spectrum of innovative digital efficiency services are the main reason for this lead market's strong digital starting position. Another good overall digital readiness score – of 70 percent – is recorded by companies in the lead market for environmentally friendly power generation, storage and distribution. Digital solutions from numerous start-ups relating to the control and integration of renewable energy and storage technologies show that, in some market segments, digital technologies are already in use today and are successfully placed on the market.

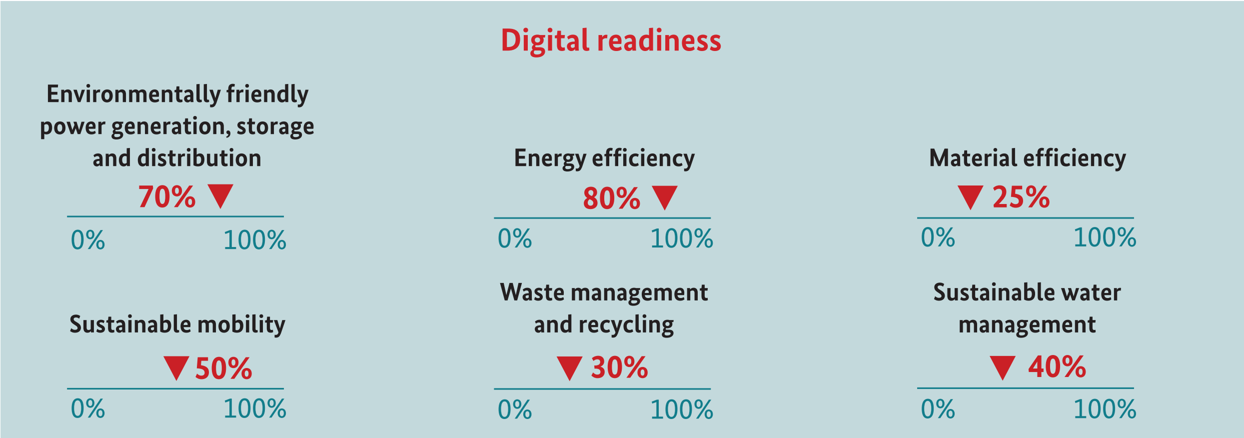
In contrast, the digital point of departure in the lead market for waste management and recycling is much weaker, with a digital readiness score of 30 percent. Only a few companies in this industry are already using digital technology or currently conducting pilot projects – in dynamic waste collection and the digital labeling of consumer goods, for example. In the lead market for material efficiency, the digital transformation is still in its early days. An overall digital readiness score of 25 percent makes this point abundantly clear. Given the complexity of the issues involved and the long-term nature of development processes in what is mostly a context of industrial production, start-up activity is still very rare. Innovation in the area of digital services is similarly sluggish.

Even in the context of Industry 4.0, the topic of material efficiency is only slowly being recognized as a relevant issue. If it is serious about retaining its role as a key player on the markets of the future, **German industry must concentrate its efforts to leverage digitalization's potential to conserve resources**.

Discrepancies between self-perception and how others see things are nothing unusual. When the companies were surveyed, one important aspect was therefore how green tech players rate their own digital capa-

2 CO_2e is the abbreviation for CO_2 equivalents.
3 Based on data from the Federal Environment Agency. See Umweltbundesamt (2017a).

bilities. One question looked at how digitalization influences different links in the value chain. Essentially, companies expect digitalization to give them a sharper competitive edge, a better knowledge of markets and customers, and new possibilities for service and cooperation.



The green transformation – Stimulus for the ecological modernization of the economy

The term “green economy” denotes an innovative economy that limits ecological risks and seizes economic opportunities. It is characterized by innovative, ecological and inclusive growth. The process of developing from the status quo to a green economy is referred to as the “green transformation”, or the “greening” of the economy. This process can also be mapped onto individual companies.

Environmental technology and resource efficiency plays a key role in advancing the green transformation. Green tech players’ products, processes and services play a crucial role in mastering ecological challenges. In its capacity as a cross-sector industry, environmental technology and resource efficiency promotes the green transformation in all branches of industry, injecting powerful stimulus for the ecological modernization of the economy. Integrated approaches and system solutions are two particularly promising aspects.

Digitalization has the potential to support and accelerate the green transformation. On the one hand, digitalization puts in place the technical conditions required for many steps to protect the environment and mitigate climate change. For example, by establishing data networks, smart system solutions can realize far greater energy savings than non-automated processes. On the other hand, digitalization facilitates the economies of scale that can make sustainable products and services cost-effective and pave the way to their wider use. Digitalization also enables information to be bundled and visualized in clear, intuitive forms. All these insights can be harnessed to further the development of ecofriendly and climate-friendly technologies and services.

2 Mitigating climate change and protecting the environment – Two global challenges

Ecological responsibility high on international and national political agendas

The international community ratified two agreements in 2015: the Paris Agreement and the UN's 2030 Agenda. The ambitious climate and environmental policy goals enshrined in these documents will promote continuing expansion of the green tech markets.

At a glance

Around the globe, it is becoming ever more important to mitigate climate change and protect the environment. Two international agreements, both signed in 2015, make the point with abundant clarity.

The Paris Agreement marks the first time that the international community has accepted a binding commitment under international law to keep global warming significantly below two degrees Celsius. Unlike the Kyoto Protocol, which obliged only industrialized nations to take steps to protect the climate, the Paris Agreement also applies to emerging nations. Starting in 2020, the industrialized nations want to set aside 100 million US dollars a year to support emerging countries in their efforts to both mitigate and adapt to climate change.

The UN's 2030 Agenda for Sustainable Development subsumes the social, environmental and economic dimensions of sustainability under 17 defined goals. Environmental technology and resource efficiency products, processes and services are needed to achieve these goals – examples include clean water and sanitation for all, affordable and sustainable energy for all, and sustainable production – and to implement the Paris Agreement. By consequence, innovations and new markets will emerge and the international lead markets for green technology will experience expansive growth. German environmental technology and resource efficiency firms can benefit from this development thanks to their experience and strong positioning on the international markets.

The Paris Agreement and the UN's 2030 Agenda – Global milestones in climate and environmental protection policy and Germany's contribution to their implementation

"The natural environment is a collective good, the patrimony of all humanity and the responsibility of everyone." This rallying cry was voiced in "Laudato si", the encyclical published by Pope Francis on June 18, 2015.[1] When the head of the Roman Catholic church places ecological issues at the heart of a teaching document addressed to the faithful throughout the world, that is powerful testimony to the tremendous importance that protecting the environment is today accorded in society and politics.

The significance of climate and environmental protection is also firmly rooted in the international community. This fact is attested by two agreements that were ratified in 2015, both of which constitute milestones in international climate and environmental protection policy: the Paris Agreement and the UN's 2030 Agenda for Sustainable Development.

Both agreements affect society and the economy – and especially the development of the green tech industry. One key lever via which they influence market activity is the enactment of national legislation in individual countries: There is a close correlation between regulatory and environmental policy frameworks on the one hand and innovation and the emergence of new markets on the other.

Paris Agreement

"Climate protectors write history"[2], "The end of fossil fuels is in sight"[3], "Turning point for the world"[4]: The staggering response to the world climate change summit in Paris was one of virtually unanimous elation. At the 21st UNFCCC climate conference (COP21)[5] in the French capital in December 2015, representatives of 195 countries and the European Union put their names to the Paris Agreement. This then came into force on November 4, 2016. For the first time ever, the international community thus shouldered a binding commitment under international law to keep the increase in the global average temperature to below

1 See katholisch.de (2016).
2 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2015a).
3 See Fücks, Ralf (2016), page 42.
4 Unattributed (2015).
5 UNFCCC stands for the United Nations Framework Convention on Climate Change; the abbreviation COP stands for "Conference of parties".

two degrees Celsius. More than that, countries would also strive to limit the temperature increase to 1.5 degree Celsius above preindustrial levels. The agreement also states that the world must become greenhouse-gas-neutral in the second half of the 21st century, meaning that it must renounce the use of fossil fuels altogether.

To achieve these ambitious targets, the following mechanisms are anchored in the Paris Agreement in order: Countries are obliged to disclose their nationally determined contributions to mitigating climate change (NDCs) every five years. Moreover, these targets are subject to the principle of progression and must become increasingly more ambitious: Scaling them back is not permitted. The NDCs are based on the national climate targets formulated by the participating nations in advance of the Paris summit. This procedure is legally binding, although the targets defined in the NDCs are not.

Reporting duties are an integral component of the Paris Agreement. Countries must regularly disclose data on their emissions of greenhouse gases to ensure that climate policy does not run aground and degenerate into mere statements of intent.

Unlike the Kyoto Protocol, which obliged only industrialized nations to take steps to protect the climate, the Paris Agreement applies to all nations. The incorporation of emerging countries is seen as a major step forward in international climate policy:[6] In recent years, the fast-growing emerging countries in particular have played a substantial role in driving up greenhouse gas emissions. If they were not involved, it would scarcely be possible to win the battle against global warming. The Paris Agreement also includes a commitment to support emerging countries in their efforts to both mitigate and adapt to climate change. One aspect is the long-term aim of promoting low-emission development in line with the goal of ensuring food security. Starting in 2020, the industrialized nations want to set aside 100 million US dollars a year for climate action funding. Via an adaptation fund, concrete measures will also be financed in regions that are most vulner-able to the effects of climate change.[7]

Core provisions of the Paris Agreement

- Keep global warming to well below two degrees Celsius while striving to limit the temperature increase to 1.5 degrees Celsius
- Cut net greenhouse gas emissions to zero by the middle of the 21st century
- Provide financial support to help emerging countries take steps to tackle climate change and adapt to its consequences
- Implement national plans to curb climate change

On June 1, 2017, US President Donald Trump announced his country's withdrawal from the Paris Agreement. It is still difficult to assess exactly what this announcement will mean in practical terms. One thing is certain, however: While the US withdrawal is a bitter blow to international climate diplomacy, it is by no means a capitulation in the face of climate change. Major sources of CO_2 emissions such as China, India, Russia and the European Union have affirmed their intention to uphold the obligations enshrined in the Paris Agreement. And even in the USA, many states are rejecting the Trump administration's climate policy volte-face, standing by their ambitious climate change mitigation targets and thus furthering the energy transition. Nearly 30 federal states have set themselves "renewable portfolio standards" that stake out a time frame for defined increases in renewable energy's share of the electricity mix.[8] New York and California rank among the pioneers and aim to meet half of all power consumption from renewable energy sources by 2030.

Many players in the US economy are likewise holding fast to climate policy targets and have sharply criticized their country's retreat from the Paris Agreement. In an open letter addressed to the Trump administration, the top managers and chief executives of leading US

6 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2015b).
7 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016a).
8 See Heinrich Böll Stiftung (2017).

companies stressed that they still feel "deeply committed" to curbing climate change and would continue to work toward the goals of reducing greenhouse gases and improving energy efficiency.[9]

The UN's 2030 Agenda for Sustainable Development

"Ours can be the first generation to end poverty – and the last generation to address climate change before it is too late."[10] In his statement to the United Nations (UN) when its sustainable development goals were resolved, then Secretary-General Ban-Ki Moon spelled out the link between development policy, mitigating climate change and sustainable development. The fight against global warming and for the conservation of natural resources is an integral element of the UN's 2030 Agenda for Sustainable Development, ratified in September 2015 at a UN Sustainable Development Summit for heads of state and government in New York. The agenda is seen to embody a new quality of international sustainability policy.

This view is rooted in the fact that the 2030 Agenda combines the environmental and developmental perspectives which, in the past, were treated separately in two distinct UN negotiating processes. The follow-up process to the Rio Earth Summit in 1992 drafted global sustainability criteria and goals. The process surrounding the Millennium Development Goals (MDGs) focused on development policy. Now, both processes have been brought together by the 2030 Agenda under the rubric "transformation towards sustainable development". The 2030 Agenda thus constitutes "a paradigm shift toward a profound transformation of [the] economy and society in north and south alike, that we might share the responsibility for shaping a sustainable and just world."[11]

The 2030 Agenda envisages a global partnership that works toward making development activities around the world socially, ecologically and economically sustainable. To this end, structures, processes, ways of thinking and patterns of behavior must be reformulated from the ground up. The 2030 Agenda is universally valid: All countries share a common responsibility for the global common good. This responsibility applies especially in areas where success can be achieved only through international cooperation, such as in mitigating climate change, preserving biodiversity, conserving natural resources, and establishing peace, security, equality and social justice.[12]

Seventeen Sustainable Development Goals (SDGs) with a total of 160 sub-targets form the core of the 2030 Agenda. Each of these goals is to be reached by the year 2030. The goals embrace all three dimensions of sustainability: the social, environmental and economic dimensions.

9 Unattributed (2017a).
10 See Deutsche Welle (2016).
11 See Bundesregierung (eds.) (2017), page 22.
12 Ibid, page 217.

Table 1: The UN's 2030 Agenda – 17 goals for sustainable development

Goals

1	End poverty in all its forms everywhere
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Ensure healthy lives and promote well-being for all at all ages
4	Ensure inclusive and equitable education and promote lifelong learning
5	Achieve gender equality and empower all women and girls
6	Ensure availability and sustainable management of water and sanitation for all
7	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduce income inequality within and among countries
11	Make cities and human settlements inclusive, safe, resilient and sustainable
12	Ensure sustainable consumption and production patterns
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Source: General Assembly of the United Nations (2015), page 15

Within the framework of the UN's Open Working Group on Sustainable Development Goals – the group that drafted the above goals – the EU strongly advocated that these goals should make due provision for challenges such as improving resource efficiency and environmental sustainability. The central political messages set forth in the preamble to the 2030 Agenda for Sustainable Development were contributed to the negotiating process largely by Germany and the European Union.

> "**People**
> *We are determined to end poverty and hunger, in all their forms and dimensions, and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment.*
>
> ***Planet***
> *We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.*
>
> ***Prosperity***
> *We are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature.*
>
> ***Peace***
> *We are determined to foster peaceful, just and inclusive societies which are free from fear and violence. There can be no sustainable development without peace and no peace without sustainable development.*
>
> ***Partnership***
> *We are determined to mobilize the means required to implement this Agenda through a revitalized Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focused in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders and all people."*[13]

Germany Sustainable Development Strategy – New Version 2016

The Sustainable Development Goals (SDGs) also apply to Germany. To implement the 2030 Agenda, each country must define its own national targets – which was done in this country in the shape of the "German Sustainable Development Strategy – New Version 2016", ratified by the German government in January 2017. This document fleshes out the 17 SDGs laid out in the UN's 2030 Agenda and links them to measurable political actions.[14]

The German Sustainable Development Strategy stakes out the measures with which the German government plans to meet the SDGs specified in the 2030 Agenda at the national level. The direction is set by the guiding principles anchored in the National Sustainable Development Strategy: intergenerational equity, quality of life, social cohesion and international responsibility. Indicators linked to medium-term and long-term goals are defined for these guiding principles. Indicator reports published every two years give account of the progress made toward achieving sustainable development.

Incorporation of the 2030 Agenda goals in the German Sustainable Development Strategy is ensured by the following concept: A political goal backed by indicators is attached to each individual SDG. The indicators are not intended to model every aspect of the topic concerned: They serve rather as key parameters highlighting those aspects that are of special importance. The indicators are analyzed by the Federal Statistical Office, which presents the current development status and uses intuitive symbols to rate the degree to which goals have been met (see Table 2).

Based on the examples of water and energy – two exceptionally vital environmental policy areas – the table below illustrates how the SDGs prescribed by the 2030 Agenda and the goals and indicators defined in the German Sustainable Development Strategy are synchronized (see Table 2).

13 Ibid, page 16.
14 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017a).

Table 2: Excerpt from the system of indicators defined for the German Sustainable Development Strategy[15]

SDG 6 Ensure availability and sustainable management of water and sanitation for all

No.	Indicator field	Indicators	Targets	Status
6.1.a	**Water quality** Reducing the pollution of water with substances	Total phosphate in flowing waters	The benchmark values for all specific types of water to be met or beaten at all monitoring points by 2030	yellow
6.1.b		Nitrate in groundwater – proportion of monitoring points in Germany at which the threshold of 50 mg/l for nitrate is exceeded	"50 mg/l" of nitrate in groundwater to be complied with by 2030	red
6.2	**Drinking water and sanitation** Better access to drinking water and sanitation worldwide, higher (safer) quality	Number of people gaining access to drinking water and sanitation through support from Germany	10 million people per year to gain access to water through 2030	green

SDG 7 Ensure access to affordable, reliable, sustainable and modern energy for all

No.	Indicator field	Indicators	Targets	Status
7.1.a	**Resource conservation** Using resources economically and efficiently	Final energy productivity	Final energy productivity to be increased by 2.1% per year from 2008 to 2050	yellow
7.1.b		Primary energy consumption	To be reduced by 20% by 2020 and 50% by 2050 compared to 2008	yellow
7.2.a	**Renewable energy** Strengthening a sustainable energy supply	Share of renewable energy sources in gross final energy consumption	To be increased to 18% by 2020, 30% by 2030 and 60% by 2050	green
7.2.b		Share of renewable energy sources in gross electricity consumption	To be increased to at least 35% by 2020, to at least 50% by 2030, to at least 65% by 2040 and to at least 80% by 2050	green

● (green) Target (almost) reached ● (yellow) Developing in the right direction ● (red) Developing in the wrong direction

Source: BMUB/Roland Berger (2017)

Climate Action Plan 2050

The Climate Action Plan 2050, ratified by the German government in November 2016, is regarded as a signpost "pointing the way to a zero-carbon Germany".[16] It shows what implementing the Paris Agreement means on the national level. Rooted in the long-term aim of establishing extensive greenhouse gas neutrality in Germany by 2050, the Climate Action Plan formulates guiding principles, milestones and measures for the following areas: the energy sector, buildings, mobility, industry and business, agriculture, land use and forestry.

The Climate Action Plan adopts the climate change mitigation targets resolved by the German government in 2010: By 2030, greenhouse gas emissions should have been reduced by at least 55 percent compared to 1990 levels. What gives the Climate Action Plan 2050 a new quality, however, is that this overall target has now been broken down across individual sectors.

15 See Bundesregierung (eds.) (2017), page 37.
16 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016b).

Progress has already been made in transforming the energy sector, for example by ramping up renewable energy. The aim is for this development to continue, and for coal-fired power generation to be rolled back accordingly.

In the buildings sector, a "roadmap for achieving a virtually zero-carbon building stock"[17] has been drawn up, including measures such as ambitious standards for new buildings, long-term strategies for refurbishing the building stock and the gradual phase-out of fossil-fuel heating systems. The objective here is to slash greenhouse gas emissions in the buildings sector by two thirds between now and 2030.

In mobility, the Climate Action Plan 2050 envisages a 40 to 42 percent reduction in greenhouse gas emissions by 2030 (compared to 1990 levels). This target is based on a series of measures, including a dedicated concept for climate policy in the road transport sector, alternative drive systems, local public transport and rail transport.

In industry and business, the goal is to cut greenhouse gas emissions by between 49 and 51 percent by 2030 (compared to 1990 levels). The German government wants to reach this goal with measures such as a research, development and market introduction program to reduce hitherto unavoidable industrial process emissions.

Importance of international and national treaties for the German green tech industry

Environmental technology and resource efficiency products, processes and services are needed to reach the goals defined in the Paris Agreement and the 2030 Agenda. Logically, therefore, the regulatory frameworks and political goals that the individual countries stake out to implement climate policy will lead to expansive development in the international green tech lead markets. In the long run, ambitious climate targets could drive investment in technologies to combat climate change that is more than a third higher than the figure forecast if current efforts to protect the climate were maintained.

German environmental technology and resource efficiency firms can benefit from this development thanks to their experience and strong positioning on the international markets. In Europe, tangible growth is expected in the lead markets for material efficiency and sustainable mobility, for example. In these lead markets, rising market volumes will give German providers the chance to sell more of their products and services. China's climate policy ambitions, which target the expansion of e-mobility[18], improvements in resource efficiency and a substantial reduction in CO_2 emissions in the energy sector, could also open up opportunities for foreign trade.

Especially in the EU member states, where demand is strong, but also in the BRICS countries,[19] Germany already enjoys a superior market position compared to its international competitors. Given this positive starting position, there are plenty of reasons why German environmental technology providers should profit from the expansion of the global green tech lead markets.

On the domestic German market, too, it is reasonable to expect that the goals set in the Climate Action Plan 2050 will prompt stronger demand for technologies that help curb emissions of greenhouse gases. This has to happen if the ambitious climate goals are to be met and Germany is to achieve extensive greenhouse gas neutrality by 2050.

Measures to attenuate climate change benefit the environment, but also generate economic "co-benefits". German green tech providers, for example, benefit from growing investment in climate action as demand for their products, processes and services increases. For companies in other industries, too, the fight against climate change is creating opportunities due to measures to enhance efficiency, for instance. Improvements in energy and material efficiency reduce resource consumption, and this is reflected in companies' cost structures. The goals set to reduce greenhouse gases promote innovation, as powerful incentives are in place to get new technological applications market-ready.

The effects of climate change can already be felt, and Germany is no exception. More and more heat waves

17 Ibid.

18 See page 49.

19 The abbreviation BRICS stands for Brazil, Russia, India, China and South Africa.

and extreme weather events such as torrential rain have been recorded in recent years. If no countermeasures were taken, climate change would have severe negative effects on agricultural, forestry and water management. This being the case, a commitment to climate policy is dictated not only by responsibility for the environment, but also by sound economic reasoning.

The framework staked out by international and national policy is a key driver of the ongoing expansion of green tech markets. In future, however, digitalization will be an indispensable aspect of efforts to master the complex challenges of climate policy and environmental protection. If global and national climate and environmental protection policy endeavors are to succeed, there is a need for systemic solutions, data connectivity and process automation. In other words, digitalization is an enabler for the continued dynamic development of environmental technology and resource efficiency as a cross-sector industry.

Technologically, green tech is already a well-developed growth market in Germany. Innovations in environmental technology and resource efficiency are being driven increasingly by systemic developments, and less by individual components. The practice of joining up individual components to form system solutions will gain further traction, with digitalization playing a key role: In most applications, digitalization creates the technological conditions for this connectivity to occur in the first place. Digital data, automation, digital user interfaces and connectivity encourage investment in green tech products that avoid or mitigate environmental impacts.

Increasingly, digitalization and the development of innovative technologies are blurring the lines between different areas of action in climate and environmental protection policy. "Innovations of relevance to the climate, such as the development of batteries and other ways to store power, are created and further developed in both transportation and automotive engineering as well as in the energy sector, for example. The advance of digitalization will reinforce this trend."[20]

20 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016c), page 60.

3 The lead markets for environmental technology and resource efficiency: Current overview

Solutions to preserve our ecosystems

Breaking green technology down into lead markets broadly demarcates the environmental technology and resource efficiency industry. Integrated environmental technologies are included in our analysis of this cross-sector industry. The technologies in the six green tech lead markets provide solutions to help preserve ecosystems, but also to help meet the fundamental needs of a growing global population.

At a glance

Environmental technology and resource efficiency is a cross-sector industry made up of six lead markets:

- Environmentally friendly power generation, storage and distribution
- Energy efficiency
- Material efficiency
- Sustainable mobility
- Waste management and recycling
- Sustainable water management

These lead markets seek to answer one key question: How can the basic needs of a growing global population be met without destroying the ecological foundations for life on planet Earth?

The breakdown into lead markets creates a consistent framework for analyzing the environmental technology and resource efficiency industry. Two subdivisions – market segments and technology lines – lay the basis for more granular analysis. The technology lines include products, processes and services and are the smallest unit in our breakdown. They are grouped together from the bottom up to form market segments.

The lead market approach facilitates comprehensive analysis of the cross-sector industry for environmental technology and resource efficiency, both with a view to the global market and focusing specifically on the German market. At the same time, it highlights the close links that exist between environmental technology and resource efficiency and the traditional branches of industry.

Various studies have already analyzed the economic significance of environmental protection and climate action. Since these publications are based on an array of differ-ent questions, however, they also vary in terms of the methodologies adopted.[1]

Our series of GreenTech publications, launched in 2007[2],builds on a concept of lead markets that broadly carves up the environmental technology and resource efficiency sector.

To master the global ecological challenges we face, we must look beyond the traditional definition of “environmental protection products” and also take account of both environmentally friendly innovations and new technologies that ease the burden on nature.

The green tech lead market approach factors integrated environmental technologies into the analysis, which also takes needs (such as mobility and the supply of water) into consideration along with the sustainable satisfaction of these needs.

A large share of the 17 Sustainable Development Goals documented in the 2030 Agenda (see Chapter 2) are closely related to the various dimensions of environmental technology and resource efficiency. Many of these goals can be met only with the aid of products, processes and services from the green tech industry. Examples include clean water and proper sanitation, affordable and clean energy, sustainable cities and communities, sustainable consumption and production, measures to mitigate climate chance and steps to protect both marine life and terrestrial life.

The six lead markets for environmental technology and resource efficiency thus span core areas that address a key question: How can the basic needs of a growing global population be met without destroying the ecological foundations for life on planet Earth?

1 For example, Federal Environment Agency studies of “Environmental Protection as an Economic Factor” have drawn on a variety of indicators for production and revenue, international trade, patents and public research spending to investigate the importance of environmental protection as an economic factor in Germany and in international comparison. The studies are based on sources such as production statistics, which permit international comparison that is rooted in exact data material. See Umweltbundesamt/Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2014).

2 See Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2007), Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2009a), Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2012), Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2015c).

Based on this conceptual premise, we have broken environmental technology and resource efficiency industry – a cross-sector industry – down into six lead markets:

- Environmentally friendly power generation, storage and distribution
- Energy efficiency
- Material efficiency
- Sustainable mobility
- Waste management and recycling
- Sustainable water management

Green tech lead markets

Key areas of environmental technology and resource efficiency are referred to as lead markets. The technologies subsumed under these lead markets provide solutions to help preserve ecosystems, but also help to meet fundamental human needs. This approach is also reflected in the political core messages that were distilled into the primary goals of the 2030 Agenda.[3]

Now well established, the lead market approach facilitates comprehensive analysis of the cross-sector industry for environmental technology and resource efficiency from both the national and global perspectives. Integrated environmental protection products, processes and services can be incorporated in this industry analysis – a vital consideration, given the growing importance of these integrated technologies. At the same time, this approach highlights the close links that exist between environmental technology and resource efficiency and the traditional branches of industry. In some cases, there are substantial overlaps with key industries such as electrical, mechanical, plant and automotive engineering, as well as the chemical sector. These overlaps and touchpoints are indeed what identify environmental technology and resource efficiency as a typical cross-sector industry.

The lines between the lead markets are, of course, not intended as a hermetic partitioning system. Approaches that transcend the boundaries of individual lead markets are of great significance, especially as system solutions grow in importance. One example is an integrated view of the electricity, heating and mobility sectors.

The breakdown into lead markets creates a consistent framework for analyzing the environmental technology and resource efficiency industry. At the same time, this framework alone is too general to permit a detailed study and presentation of the many and varied trends and dynamics in the green tech industry. That is why we have added two subdivisions – market segments and technology lines – as the basis for more granular analysis. The resultant three-tiered structure facilitates in-depth analysis at varying levels of abstraction. The big picture – a panorama of the whole branch of industry and its lead markets – highlights the main developments in the green tech industry today and the outlook for the future (see “Methodology: The basis for our market forecasts” on page 35).

Technology lines are the smallest unit in our breakdown. As such, they serve as the basis for segmentation of the environmental technology and resource efficiency industry. The term “technology line” includes products, processes and services. Technology lines are grouped together from the bottom up to form market segments, which, in turn, lay the foundation for the lead markets. Figure 1 shows which market segments are assigned to each of the six lead markets for environmental technology and resource efficiency. The remainder of this chapter then takes a closer look at the segmentation of the individual lead markets.

3 See General Assembly of the United Nations (2015), page 2.

Figure 1: The six lead markets for environmental technology and resource efficiency and their market segments

1 Environmentally friendly power generation, storage and distribution

- Renewable energy
- Ecofriendly use of fossil fuels
- Storage technologies
- Efficient grids

2 Energy efficiency

- Energy-efficient production processes
- Energy-efficient buildings
- Energy-efficient appliances
- Cross-sector components

3 Material efficiency

- Material-efficient processes
- Cross-application technologies
- Renewable resources
- Protection of environmental goods
- Climate-adapted infrastructure

4 Sustainable mobility

- Alternative drive technologies
- Renewable fuels
- Technologies to increase efficiency
- Transportation infrastructure and traffic management

5 Waste management and recycling

- Waste collection, transportation and separation
- Material recovery
- Energy recovery
- Landfill technologies

6 Sustainable water management

- Water production and treatment
- Water system
- Wastewater cleaning
- Wastewater treatment methods
- Efficiency gains in water usage

Source: Roland Berger (2017)

The lead market for environmentally friendly power generation, storage and distribution

Global energy consumption stood at 13,276.3 million TOE[4], a good one percent more than in the previous year.[5] Yet many millions of people around the world are still forced to live without electricity. This failing is addressed by SDG 7 in the 2030 Agenda, which demands that we "Ensure access to affordable, reliable, sustainable and modern energy for all".[6]

In light of global population growth and ongoing industrialization in emerging countries, demand for energy will continue to increase around the world. In its "New Policies Scenario", the International Energy Agency (IEA) predicts that global demand for energy will rise by roughly one third by 2040.[7] This prediction is based on the assumption that 9.2 billion people will inhabit the planet in 2040 (2015: 7.2 billion).

Fossil fuels currently dominate the world's primary energy mix. Oil, gas and coal together account for 85 percent of primary energy consumption worldwide.[8] The energy industry is thus responsible for around two thirds of global greenhouse gas emissions[9] – a statistic that underscores the key role played by the energy sector in the fight against global warming. In its latest World Energy Outlook, the IEA writes that: "The Paris Agreement on climate change, which entered into force in November 2016, is at its heart an agreement about energy."[10] It adds that a transformative change in the generation of power and heat is essential to reach the objectives of the Paris Agreement.

There are four key levers to decarbonize[11] the energy sector: (1) improving energy efficiency[12], (2) increasing the use of renewable energy sources, (3) reducing resource consumption and (4) reducing harmful emissions from the use of fossil fuels.

In recent years, efforts to increase the use of renewable energy have made progress that, in the past, would have been consigned to the realms of science fiction. The global installed capacity of plants using renewable energy was 921 gigawatts in 2016. 176 countries have signed up to the goal of expanding renewable energy and backed these plans with concrete development mechanisms.[13] In its "New Policies Scenario", the IEA reckons that, by 2040, renewable energy will account for 37 percent of the world's gross electricity generation.[14]

4 TOE = tonne(s) of oil equivalent: a unit of measurement for the energy contained in energy resources, or for energy consumption. 1 kilogram of oil equivalent (KGOE) = 41,868 joules = 11.63 kW. A tonne of oil equivalent (TOE) is equal to 1,000 KGOE.
5 See BP Statistical Review of World Energy June 2017, page 8.
6 See General Assembly of the United Nations (2015), page 15.
7 See International Energy Agency (2016a): World Energy Outlook. Summary, page 1.
8 See BP Statistical Review of World Energy June 2017, page 9.
9 See International Energy Agency (2016a), page 1.
10 Ibid.
11 The term "decarbonization" stands for the increasing use of low-carbon energy sources. In the long term, decarbonization means reducing or abandoning the use of fossil fuels that harm the environment. See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016c), page 21 and page 64.
12 Since energy efficiency is a lead market in its own right, it is not discussed further at this point.
13 This figure does not include hydroelectric power generation. If hydropower plants were also taken into account, the installed capacity of plants using renewable energy would be 2,017 gigawatts (see REN 21 Renewable Energy Policy Network for the 21st Century (2017), page 21).
14 See International Energy Agency (2016a), page 5.

Coal, gas and oil will continue to play a major role in the global energy mix in the decades to come. This being the case, technologies that support the withdrawal from fossil fuels, promote the use of renewable energy sources and minimize resource consumption and harmful emissions in fossil-based power generation on an international level – thereby reducing the environmental impact of the use of fossil fuels – are absolutely essential in the medium and long term.

Germany's climate policy likewise focuses on the energy sector, which accounts for nearly 39 percent of total emissions (2015).[15] In 2016, renewable energy's share of gross electricity generation was 29 percent.[16] Thanks to the stepped-up the use of renewable energy sources and improved energy efficiency, greenhouse gas emissions from the country's energy sector have declined considerably in the past few decades, falling by 26.5 percent between 1990 and 2016.[17]

Ways to enhance flexibility are an essential precondition for the decarbonization of the energy sector. If the share of renewable energy sources such as photovoltaics and wind power is increased, load management too must be improved and substantially more energy storage capacity must be made available. Fluctuations in the power fed into the grid from renewable sources makes it more challenging to keep the grid stable by maintaining an equilibrium state between the supply of and demand for electricity. Advances in storage technologies should enable temporary surpluses in the supply of or demand for electricity from renewable sources to be absorbed, while also allowing electricity from renewable sources to be used across sectoral boundaries.
The challenges that lie along the path to a resource-friendly and climate-compatible energy supply break down into four areas where action is needed: renewable energy, the ecofriendly use of fossil fuels, storage technologies and efficient grids. These areas also constitute the eponymous market segments in the lead market for environmentally friendly power generation, storage and distribution (see Figure 2).

Figure 2: Market segments and key technology lines in the lead market for environmentally friendly power generation, storage and distribution

Environmentally friendly power generation, storage and distribution

Renewable energy	Ecofriendly use of fossil fuels	Efficient grids	Storage technologies
• Photovoltaics • Solar thermal energy • Solar thermal power plants • Wind power (onshore) • Wind power (offshore) • Geothermal power • Hydropower	• Gas and steam power plants • Cogeneration units • High-capacity power plants • Carbon capture and storage (CCS) • Waste heat recovery	• Control technologies for grids • Control technologies for plants • Heating and cooling networks • Metering and consumption measurement systems • ICT ("Internet of energy")	• Mechanical storage of energy • Electrochemical storage of energy • Electronic storage of energy • Thermal storage of energy • Chemical storage of energy • Power2X

Source: Roland Berger (2017)

15 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017b), page 27.
16 See Bundesministerium für Wirtschaft und Energie (2017a).
17 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017c), page 28.

The lead market for energy efficiency

Energy efficiency

Energy productivity (economic output per unit of energy required) and energy intensity (energy required per unit of economic output) are used as indicators of energy efficiency. To increase energy productivity or reduce energy intensity is to wean economic growth off its dependency on energy consumption and is thus a precondition of sustainable growth. In other words, the aim must be to add as much value as possible with as little energy as possible.

Energy efficiency is a key tool to reduce greenhouse gas emissions. Every kilowatt-hour that is not consumed does not have to be generated in the first place. In the 29 member states of the International Energy Agency (IEA), energy efficiency improved by 14 percent between 2000 and 2015. In 2015 alone, that saved 450 million tonnes of oil equivalent worldwide[18] – a figure that roughly equates to Japan's total primary energy consumption in the same year.[19] In addition, scaled-back energy consumption saved the world about 540 billion US dollars in energy spending.[20]

Notwithstanding, the rate at which energy efficiency is improving is not enough to make an adequate contribution to a sustainable, climate-friendly energy sector on a global scale. The IEA believes that around two thirds of existing potential to increase energy efficiency still remains untapped.[21]

Improving energy efficiency is very high on the energy and climate policy agenda in Europe. "Efficiency first" was the motto under which the European Union updated its Energy Efficiency Directive in November 2016. Between now and 2030, the aim is to improve energy efficiency in the EU's member states by 30 percent. To put that another way: Nearly a third less energy should be consumed than in a benchmark scenario that takes no account of energy efficiency measures.

Final energy productivity is used in Germany as one of several sustainability indicators. In the period from 2008 through 2050, the objective is to increase final energy productivity by 2.1 percent a year. Calculations by the Federal Statistical Office point to a 9.3 percent increase in final energy productivity in the years from 2008 through 2015. That works out at an average annual gain of 1.3 percent – a positive trend, but still not enough.[22]

To further improve energy efficiency, a strong focus will be placed on the four areas of action that together make up the lead market for energy efficiency. The structure of the market segments in this lead market reflects those consumer groups that harbor the greatest potential for energy savings: industry, commerce, the service sector and the real estate industry (see Figure 3). The market segment for energy-efficient production processes concentrates on the core processes in a variety of industries. With this central focus, it offers companies ways to optimize their processes and thereby reduce their energy consumption. The technology lines in this segment (see Figure 3) cover important industries such as basic chemicals, retail and logistics, automotive engineering, food production, the metal production industry, metalworking, and paper and cardboard manufacturing.

18 See International Energy Agency (2016b), page 13.
19 See BP Statistical Review of World Energy June 2017, page 9.
20 See International Energy Agency (2016b), page 13.
21 Ibid.
22 See Statistisches Bundesamt (2017a), page 47.

Figure 3: Market segments and key technology lines in the lead market for energy efficiency

Energy efficiency

Energy-efficient production processes	Energy-efficient buildings	Energy-efficient appliances	Cross-sector components
• ... in the metal producing industry • ... in basic chemicals • ... in automotive engineering • ... in mechanical engineering • ... in retail/logistics • ... in metalworking • ... in paper and cardboard manufacturing • ... in plastics processing • ... in food production • ... in the manufacture of mineral products • ... in the manufacture of glass and ceramic products	• Thermal insulation • Building automation • Passive houses/ PlusEnergy houses • Efficient heating, ventilation and air-conditioning systems	• Energy-efficient white goods • Green IT • Energy-efficient lighting • Energy-efficient consumer electronics	• Measurement and control instrumentation • Process control instrumentation • Pump systems • Ventilators • Electric drive systems • Heat exchangers • Compressors, compressed air and vacuum technology

Source: Roland Berger (2017)

Saving energy in the building sector is another essential element in efforts to reduce both energy consumption and greenhouse gas emissions. Energy-efficient buildings constitute a separate market segment comprising four main technology lines: efficient heating, ventilation and air-conditioning (HVAC) systems, building automation, thermal insulation, and passive houses/PlusEnergy houses.

An additional market segment covers energy-efficient appliances. The focus here is on ways in which companies and private consumers can save energy in the operation of electrical appliances. The latter break down into white goods, consumer electronics, lighting, and information and communication technology (green IT).

The market segment for cross-sector components groups together technology lines that help companies in any industry to save energy in what can be referred to as auxiliary production processes.[23] Electric drive systems, compressors, compressed air and vacuum technology, pump systems, process control instrumentation, ventilators, heat exchangers and measurement and control instrumentation all belong to this segment.

23 The auxiliary processes are also referred to as production subsystems.

Goals and measures defined in Germany's National Action Plan on Energy Efficiency (NAPE) (2014)[24]

Taking 2008 as the base year, primary energy consumption in Germany is to be reduced by 20 percent by 2020 and 50 percent by 2050. By 2020, final energy consumption for heating is to be 20 percent lower, while power consumption and final energy consumption in the transportation sector is to be 10 percent lower, again relative to 2008 as the base year.[25]

To meet these targets, the NAPE contains a series of measures with varying time frames:

- Quality assurance and optimizing existing federal energy consulting
- Upgrading the KfW development bank's CO_2 Building Renovation Program and improving KfW's Energy Efficiency Programs to promote corporate investment in energy-efficient technologies
- Introducing "STEP up!" as a competitive tendering model for energy efficiency
- Launching the Energy Efficiency Networks Initiative
- Compelling non-SMEs to conduct energy audits in accordance with DIN EN 16247-1 and to repeat them every four years
- Passing the "Energy Transition Digitalization Act", which did indeed come into force on August 29, 2016 and which now governs regulations and obligations concerning the introduction of smart measuring systems on the part of both energy producers and consumers[26]
- Promoting energy performance contracting
- Establishing a national energy efficiency label for heating installations etc.

24 See Bundesministerium für Wirtschaft und Energie (2017b), page 9.
25 See Bundesministerium für Wirtschaft und Energie (2017c), page 4.
26 Came into force on August 29, 2016.

The lead market for material efficiency

In 2017, what is known as Earth Overshoot Day came on August 2. Every year, the Global Footprint Network organization works out the date on which humanity overdraws its resource account for that year – the date by which we have used more of the Earth's resources than are theoretically available to meet the needs of the world's population in that year. The calculation is based on humanity's ecological footprint; and by this measure, we would currently need 1.7 Earths to satisfy our need for resources.[27] If our consumption of raw materials continues to increase unbridled, we will need two planet Earths a year by 2030[28] – which will overstretch the capacity of our ecosystems.

There are a number of reasons why the consumption of raw materials is increasing worldwide. Population growth, the spread of resource-intensive patterns of consumption and industrialization in many emerging nations are keeping demand for raw materials at a high level.

Statistically, every person in Germany consumes more than 16 tonnes of metal, concrete, wood and other materials every year. That is 44 kilograms a day. The figures for the UK and France are similar. In Japan, consumption of raw materials is about a third lower. Australia consumes about three times as much raw material per capita as Germany.[29]

Cultivating an efficient and environmentally friendly approach to raw materials is one of the keys to the sustainability of our economic and social systems. Due consideration must also be given to the scarcity of resources, the need to protect the environment and the need to curb climate change.

The term "resource scarcity" is interpreted incorrectly almost as frequently as it is used. It is not usually a reference to physical scarcity, where deposits of certain raw materials are nearing exhaustion: It is rather taken to mean relative scarcity, which arises from "geological, technical, structural, geopolitical, socioeconomic and ecological contribution factors" in relation to given demand.[30] Relative scarcity is determined by means of criticality analyses. On this basis, organizations such as the European Commission and Germany's Federal Institute for Geosciences and Natural Resources (BGR) publish lists of critical raw materials for the European and German economies respectively.

27 See Earth Overshoot Day (2017).
28 See World Wildlife Fund (2017).
29 See Umweltbundesamt (2016a), page 47.
30 Ibid, page 11.

Figure 4: Market segments and key technology lines in the lead market for material efficiency

Material efficiency

Material-efficient processes

- Manufacture of metal products
- Manufacture of plastic products
- Processes in the chemical industry
- Paper and pulp production
- Processes in the building industry
- Production in the publishing and printing industry
- Manufacture and processing of wood products and wood materials
- Electricity generation and distribution equipment
- Paper and cardboard products

Cross-application technologies

- Biotechnology
- Nanotechnology
- Organic electronics

Climate-adapted infrastructure

- Storm protection
- Heat and fire protection
- Flood protection

Renewable resources

- Bioenergy for heat and power generation
- Feedstock for the chemical industry
- Bioplastics
- Composite materials
- Natural cosmetics
- Natural insulating materials
- Oils/fats from RR[1)]
- Paints/varnishes from RR[1)]

Protection of environmental goods

- Soil protection
- Noise protection
- Groundwater protection/water conservation
- Prevention of air pollution
- Nature and landscape conservation

1) RR – renewable resources

Source: Roland Berger (2017)

The world's voracious appetite for raw materials places a heavy burden on the environment. The ecological consequences of extracting and processing raw materials are immense. Mining raw materials mostly does serious damage to nature and the countryside, as well as posing health risks to people in the regions affected. Substantial volumes of greenhouse gases are released into the atmosphere during the extraction, transportation and processing of raw materials.

Both ecological and economic arguments are compelling us to wean economic development off the consumption of raw materials and, in so doing, to minimize the harmful environmental impacts that accompany the extraction of raw materials. In this context, improvements to material efficiency must make a major contribution. This fact is mirrored in material productivity, which is another of the indicators in Germany's Sustainable Development Strategy. Back in 2015, the German government launched its resource efficiency program ProgRess to underscore its commitment to the goal of raising material productivity. In the years from 2000 to 2010, material productivity increased by an average of 1.5 percent per year. This trend is continuing.[31]

The lead market for material efficiency encompasses technologies and methods that reduce the consumption of non-energy resources (metals such as iron and copper and non-metallic resources such as minerals, for example) and materials.[32] Resource efficiency is the overriding theme in both energy efficiency and material efficiency. The technologies and methods employed in achieving energy efficiency constitute a lead market in their own right. Resource efficiency refers to efficiency in extracting raw materials, while material efficiency means efficiency in processing them. The production of goods in industry and commerce is the principal arena in which the technologies in this lead market are applied (see Figure 4).

The market segment for material-efficient processes takes examples from various industries to show how companies can both cut costs and protect the environment. In the market segment for cross-application

31 See Statistisches Bundesamt (2017a), page 52f.

32 Resources used for food production and water management are not taken into account in this lead market.

technologies, biotechnology, nanotechnology and organic electronics are described insofar as they apply to material efficiency. Cross-application technologies is the name given to technologies that are relevant to a wide range of industries rather than to one specific industry: Biotechnology, nanotechnology and organic electronics all fit into this category. All three are key to the ongoing development of material-efficient products and processes.

Renewable resources constitute the third segment of this lead market. Replacing finite fossil resources with renewable resources plays an important part in fostering the sustainable use of resources. Accordingly, technology lines such as feedstock for the chemical industry and natural cosmetics have been assigned to this market segment. These technology lines include products and processes that help industry move away from oil and toward renewable resources. The natural cosmetics technology line includes cosmetic products that are produced using renewable resources. One distinctive feature of natural cosmetics is that they contain no paraffin, silicones or any other petroleum-based products.

The relationship between growing demand for raw materials, the increasing extraction thereof and the resultant risks and damage to ecosystems is the conceptual basis on which we decided to include the protection of environmental goods as a separate market segment in the lead market for material efficiency. This market segment also covers the renaturation of sites adversely affected by raw material extraction, alongside environmentally friendly methods of extracting raw materials. The market segment for climate-adapted infrastructure encompasses technologies that are used for protection from storms, heat, fire and flooding. The basic idea is that preventing damage caused by extreme weather events not only protects human life, but also helps to attenuate demand for materials by safeguarding buildings and infrastructure.

The lead market for sustainable mobility

The world's roads are set to become ever more congested. Vigorous expansion in the transport sector is anticipated in the decades ahead. In terms of passenger kilometers, global transportation will probably more than double between 2015 and 2050. Freight volumes are likely to more than triple in the same period. In 2050, around 2.4 billion vehicles are expected to be in circulation worldwide – up from the one billion vehicles counted in 2015.[33]

This forecast was published by the International Transport Forum (ITF) in its "Transport Outlook 2017". This annual publication analyzes the trends that are shaping the global transport sector. As far as the need to mitigate climate change is concerned, the prospects are alarming: If nothing is done to counter this development, greenhouse gas emissions from the transport sector could leap by as much as 60 percent by 2050.[34] Any such course of events would be a setback for the climate. As things stand, the transport sector accounts for 24 percent of the world's CO_2 emissions.[35] That figure is about 20 percent in Europe and 18 percent in Germany.[36, 37]

Extremely heavy dependency on oil is still largely responsible for the greenhouse gas emissions caused by the transport sector and the damage they do to the climate. Data from the International Energy Agency (IEA) puts oil's share of final energy consumption in the global transport sector at 93 percent.[38] Europe is no different: Here, oil meets 96 percent of the transport sector's demand for energy. It is the key resource for the continent's mobility.

If we are to have any chance of winning the fight against global warming, greenhouse gas emissions from the transport sector must be reduced. By 2050, the EU must slash traffic-related emissions by at least 60 percent compared to 1990 if it is to achieve its climate policy targets. "We need to both accelerate innovation and make radical policy choices to decarbonize transport," said José Viegas when presenting the Transport Outlook 2017.[39] This appeal is directed equally to Germany, where the transport sector must make an ambitious contribution if national climate action targets are to be met. The Climate Action Plan 2050 states that the transport system in Germany should

33 See International Transport Forum (2017a).
34 Ibid.
35 See International Energy Agency (2016c), page 97.
36 See Eurostat (2017).
37 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016d), page 30.
38 See International Energy Agency (2017).
39 See International Transport Forum (2017b).

be virtually decarbonized – free from dependency on fossil fuels containing carbon, and hence largely greenhouse-gas-neutral – by 2050. As a milestone along the road to this target, the aim is to reduce greenhouse gas emissions in the transport sector to between 95 and 98 million tonnes of CO_2 equivalent by 2030. To put that in perspective: The figure for 2014 was 160 million tonnes of CO_2 equivalent.[40]

The increase in traffic, especially on the roads, harms more than just the environment: Particulates, nitrogen oxide and traffic noise also endanger human health, above all in urban areas. Around the globe, air pollutants cause the death of more than 3.5 million people a year.[41] The number of these deaths rose by 4 percent between 2005 and 2010 – a trend due in part to the worsening smog issue in China and India. In Germany, particulates are responsible for 42,000 premature deaths and over 300,000 years of lost health.[42]

Against a backdrop of climate policy and environmental pollution, it is clear that the transport sector needs to chart a new path. There is no question that mobility is a basic human need and the foundation for complex modern national economies. By the same token, however, there is no question that mobility must be made sustainable. Fundamentally, the issues at stake are minimizing the damage to people and the environment and ensuring that growing traffic volumes do not inexorably increase traffic-related energy consumption and greenhouse gas emissions.

In conjunction with the ongoing digitalization of the transport sector, new technologies create the opportunity to shape mobility in a way that is kinder to the climate and to the environment. "Technological progress can deliver around 70 percent of potential CO_2 reductions through 2050. Reductions beyond that demand a new approach to mobility. In this area, there is still plenty room for maneuver. We need to do a lot more thinking about things like 'shared mobility', modified logistical chains and even new modes of transport," stresses ITF Secretary General José Viegas.[43]

Trusting to technological solutions alone will not be sufficient to carry a sustainable mobility transformation, though. Additional incentives and a more conducive framework are also needed if people are to change their individual mobility habits. Examples include attractive local public transport offerings and an approach to urban planning and infrastructure that breaks out of the car-centric mindset.

Sustainable transformation of the transport sector demands an integrated approach that combines traffic reduction, shifting traffic to climate-friendly modes of transport and improving efficiency in order to curb emissions. It is not just about substituting combustion engines with alternative drive systems such as e-mobility: The aim must be for sustainable urban and regional development to shape individual mobility for people and goods without leading to an inevitable increase in motorized road traffic. These challenges are the central areas where action is needed in the lead market for sustainable mobility, which breaks down into four market segments.

The market segment for alternative drive technologies comprises electric, hybrid and fuel cell drive systems (see Figure 5). As these technologies develop, penetrate the market and increasingly present genuine alternatives to conventional combustion engines, this will help decarbonize the transport sector and roll back dependency on oil-based fuels. The technology lines in the alternative fuels market segment serve the same goal.

Meanwhile, combustion engines must become more efficient if CO_2 emissions are to be minimized in the transport sector. The products and technologies needed to do so are subsumed under the market segment for technologies to increase efficiency.

In the market segment for transportation infrastructure and traffic management, innovative measures and technologies will reduce mobility-related emissions. Smart transportation concepts that link up individual modes of transport have an important part to play here.

40 See Bundesministerium für Umweltbau, Naturschutz, Bau und Reaktorsicherheit (2016b).
41 See Organisation for Economic Co-operation and Development (2014).
42 Ibid.
43 See International Transport Forum (2017b).

Figure 5: Market segments and key technology lines in the lead market for sustainable mobility

Sustainable mobility

Alternative drive technologies	Renewable fuels	Technologies to increase efficiency	Transportation infrastructure and traffic management
• Hybrid drive systems • Electric drive systems • Fuel cell drive systems	• Bioethanol • Biodiesel • Biomethane • Hydrogen from renewable resources • Biokerosene	• Efficiency gains in combustion engines • Lightweight engineering technologies • Energy-saving tires	• Rail vehicles and infrastructure • Traffic control systems • Public transport • Filling station infrastructure for alternative drive systems • Car sharing • Cycle paths

Source: Roland Berger (2017)

The lead market for waste management and recycling

Around the globe, piles of waste are swelling to become gigantic mountain ranges. If concerted action is not taken, humanity will be producing 11 million tonnes of waste per day in 2100, according to the "business as usual" scenario outlined in the World Bank's study *What a Waste: A Global Review of Solid Waste Management*.[44] The volume of waste is unequally distributed around the world. Most of it is produced in the industrialized nations of Europe and North America, and there are signs that the volume of waste will increase as many emerging countries press ahead with economic development. The authors of the World Bank study expect waste production in the OECD countries to peak in 2050. The quantity of waste in East Asia will probably peak in 2075.

The rule of thumb is that waste volumes tend to be higher in largely urban regions. To remove the waste amassed every day in our cities, a convoy of 5,000 trucks would need to roll up.[45]

The World Bank study puts spending on waste management at 205 billion a year US dollars. Yet the growing mountains of waste exact a heavy toll not only in economic terms, but also on the environment. In most emerging nations, the infrastructure for waste disposal is inadequate or simply non-existent. Unregulated storage, illegal dumping and open-air incineration create significant environmental pollution and pose serious health risks. Contamination of the soil, groundwater and surface water damages ecosystems. The inappropriate treatment and dumping of waste also has severe repercussions for the climate. The fermentation of organic matter creates landfill gases that contain methane, which is harmful to the climate.

To keep the waste heaps from reaching to the skies, waste management and recycling must be ramped up around the globe. Two aspects are key: waste avoidance and the recovery of reusable materials.[46] By fostering the reuse of waste, the lead market for waste management and recycling has the potential to reduce inputs of primary raw materials and the burden on the environment associated with their extraction. The tremendous importance of waste avoidance and recycling is mirrored in the ideal of the full-cycle concept. This model of closed material cycles follows the principles seen in natural ecosystems that produce no waste, instead converting all materials into reusable resources.

Further recycling options must be further developed to scale back demand for primary raw materials, but not only in light of ecological considerations. Waste management and recycling is also a powerful tool to lessen the impact of scarcity and volatile prices on the raw material markets. There are sound economic reasons, too, why this should be done: The German economy is heavily dependent on raw material imports. And for industrial companies in particular, highly volatile prices on the raw material markets are a major headache. Beyond that, numerous raw materials are also exposed to significant procurement risks: The list of raw materials published in 2016 by the German Mineral Resources Agency (DERA) affirmed that 114 of the 300 raw materials examined were subject to "high potential procurement risks" due to the concentration of supply and enhanced country risks.[47] DERA warns that: "The distortion of competition, trade conflicts, speculation, political measures or natural disasters can quickly transform potential procurement risks into real pricing and delivery problems."

The guiding principles established for waste management and recycling map out a five-tiered waste hierarchy with the following priority order: prevention, preparation for reuse, recycling, other recovery (in

44 See World Bank (2013).
45 Ibid.
46 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016e), page 8.
47 See Deutsche Rohstoffagentur (2017).

particular energy recovery) and disposal. Precedence is given to the best option in light of environmental considerations, although ecological, technical, economic and social consequences must also be analyzed. This waste hierarchy is anchored in the EU's Waste Framework Directive (Directive 2008/98/EC). In Germany, this directive was translated into national law by the Waste Management and Recycling Act (KrWG), which came into force in 2012, superseding the Recycling and Waste Act (KrW/AbfG) ratified in 1996.

In charting this regulatory course, Germany was quick to adopt a rigorous waste management and recycling policy. It thus succeeded in severing the ties that bound the trend in waste volumes to economic output. The relevant indicator here is waste intensity,[48] which fell by 25.9 percentage points in the period from 2000 through 2015.[49] Recycling rates, too, have improved continually. A single example suffices to illustrate the point: In 1990, 87 percent of household waste was declared to be residual waste. Only 13 percent was treated as reusable materials (biodegradable waste, glass and paper). By 2013, this ratio had experienced a radical shift: Of the 43.9 million tonnes of household waste recorded in this year, 15.3 million tonnes (35 percent) ended up as residual waste, while 28.6 million tonnes of biodegradable waste, glass, paper and packaging waste found its way into recycling bins.[50]

The above waste hierarchy creates a framework within which to identify distinct market segments in the lead market for waste management and recycling (see Figure 6). The services and infrastructures subsumed under the market segments for waste collection, transportation and separation lay the foundation for waste management and recycling. The market segment for material recovery comprises the technology lines for mechanical recycling and feedstock recycling. Mechanical recycling refers to recycling processes in which the materials and their chemical structure are not altered. One example is the remelting of plastic waste to produce granulate. Feedstock recycling treats substances in a way that changes their chemical structure – deriving oils, waxes and gases from plastic waste, for example.

One widespread form of energy recovery is thermal waste treatment, which involves incinerating waste and using the energy released by this process to supply heat and generate power. The use of organic waste in biogas plants is another variation on the same theme.
Waste that is not suitable for material or energy recovery must be disposed of in an environmentally friendly manner. The landfill technologies market segment brings together those technology lines that serve this purpose.

Figure 6: Market segments and key technology lines in the lead market for waste management and recycling

Waste management and recycling

Waste collection, transportation and separation
- Waste collection and transportation
- Waste separation

Material recovery
- Mechanical recycling
- Feedstock recycling

Energy recovery
- Power generation
- Heat generation

Landfill technologies
- Building landfill sites
- Sealing of landfill sites
- Redeveloping landfill sites

Source: Roland Berger (2017)

48 Waste intensity is defined as the ratio of the total waste volume to gross domestic product.
49 See Umweltbundesamt (2017b).
50 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016e), page 12.

The lead market for sustainable water management

Clean water and access to sanitation for all is one of the stated aims of the 2030 Agenda. Yet today, nearly 750 million people do not have access to clean water, and around 2.5 billion people have to get by with only inadequate sanitation or none at all.[51]

Sustainable Development Goal 6 explicitly addresses the quality and management of global water resources: "Water and sanitation are at the very core of sustainable development, critical to the survival of people and the planet."[52] Water plays a vital role for humanity: Food, health, the environment and economic development all depend on a sufficient supply of good quality water. Yet a sufficient supply of good quality water is precisely the issue at stake in many of the world's regions. Taken together, population growth, rising incomes and urbanization are driving up global demand for water. Since 1980, the water extraction volume has increased by one percent per year.[53] And then there are the effects of climate change to contend with: Global warming will affect the availability of water in many regions of the world. At the same time, extreme weather events such as heat waves and torrential rain will be more frequent and more intense. This in turn will have consequences for the water supply.

Agriculture accounts for the largest share of water use (70 percent) in the world.[54] As demand for food increases in line with a growing global population, the proportion of irrigated farmlands will likewise rise. That will place an added burden on the water balance and/or lead to water shortages in the regions affected.

These developments do not bode well: "If current water management policies persist, and climate models prove correct, water scarcity will proliferate to regions where it currently does not exist, and will greatly worsen in regions where water is already scarce. [...] Reduced freshwater availability and competition from other uses – such as energy and agriculture – could reduce water availability in cities by as much as two thirds by 2050, compared to 2015 levels."[55] In a business-as-usual scenario, the discrepancy between global demand for water and the global supply of water will stand at 40 percent.[56]

51 See Welthungerhilfe (2017a).
52 See United Nations, Department of Economic and Social Affairs (2017).
53 See UNESCO (2016), page 3.
54 See UNESCO (2015), page 11.
55 World Bank (2016), page 1.
56 See UNESCO (2015), page 11.

Declining water supplies are already causing some countries to suffer. The US state of California has been plagued by a five-year drought that ended abruptly with extremely heavy rains in February 2017. In April 2016, Chinese news agencies reported that provinces in the north of the country were experiencing a severe drought. Around 200,000 farmers and 80,000 large animals were suffering from a lack of drinking water.[57] Even Brazil, a country with one of the most plentiful supplies of water in the world, was struck by a water crisis in 2015 that led to the "blue gold" being rationed in some cities.[58]

Ensuring a reliable water supply is not only a question of quantity, but also of quality. In many places, the pollution of water resources exacerbates the problem of supply. Fertilizers and pesticides produce pollutants that pass into groundwater, for example. In emerging countries, as much as 90 percent of household and commercial effluent flows untreated into lakes, rivers and the sea.[59]

The global water crisis can be eased and the goal of "clean water and sanitation" formulated in the 2030 Agenda achieved only through sustainable management of water resources – meeting the basic needs of current generations without endangering the livelihood of the generations to come. This can be done with the aid of environmental technology. The lead market for sustainable water management splits into five market segments that, together, model the various stages in the water management cycle (see Figure 7).

The market segment for water production and treatment models the first stage in this cycle. It incorporates products and processes to develop and extract fresh water resources, monitor groundwater and plan, build and operate water treatment plants.

The water system market segment spans all elements in the water distribution system that facilitate the transportation of fresh water from water treatment plants to consumers. In the other direction, it covers the transportation of wastewater from consumers to wastewater treatment plants. Wastewater cleaning and wastewater treatment methods are two further segments of the market for sustainable water management.

The market segment for efficiency gains in water usage covers a broad spectrum of products, processes and services that help us to handle water resources efficiently. Examples include water measurement instruments and water management systems. The technology lines in this market segment reflect the different groups of users: private households, commerce and industry, and agriculture.

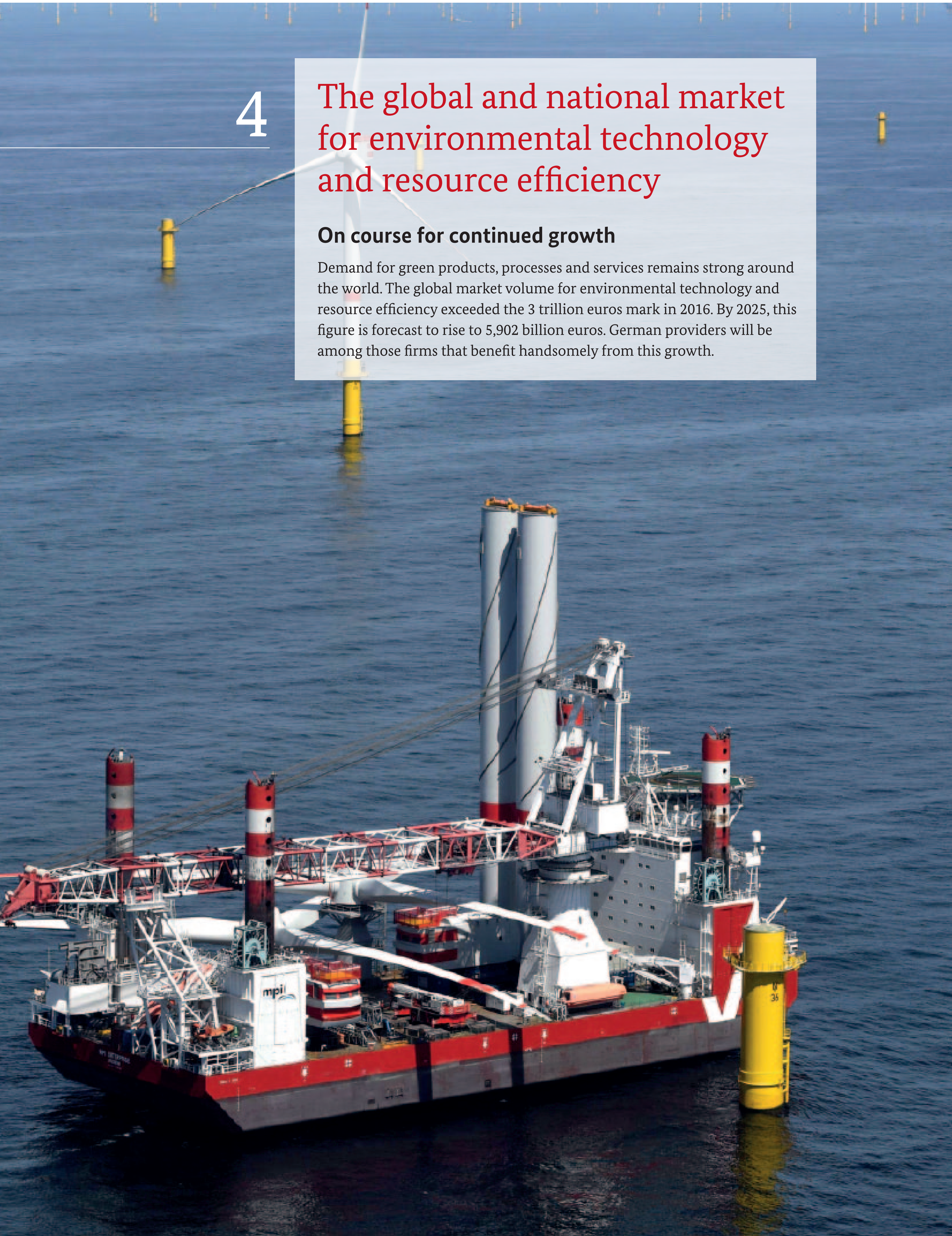
57 See China Observer (2016).
58 See Deutschlandfunk (2015).
59 See Welthungerhilfe (2017b).

Figure 7: Market segments and key technology lines in the lead market for sustainable water management

Sustainable water management

Water production and treatment	Water system	Wastewater cleaning	Wastewater treatment methods	Efficiency gains in water usage
• Water production • Water treatment • Innovative sanitation systems	• Water distribution • Wastewater collection and transportation	• Sewage sludge treatment • Energy management in wastewater treatment plants • Recovery of materials in wastewater	• Wastewater treatment	• Water efficiency technology in households • Water efficiency technologies in agriculture • Water efficiency technologies in commerce and industry

Source: Roland Berger (2017)



4 The global and national market for environmental technology and resource efficiency

On course for continued growth

Demand for green products, processes and services remains strong around the world. The global market volume for environmental technology and resource efficiency exceeded the 3 trillion euros mark in 2016. By 2025, this figure is forecast to rise to 5,902 billion euros. German providers will be among those firms that benefit handsomely from this growth.

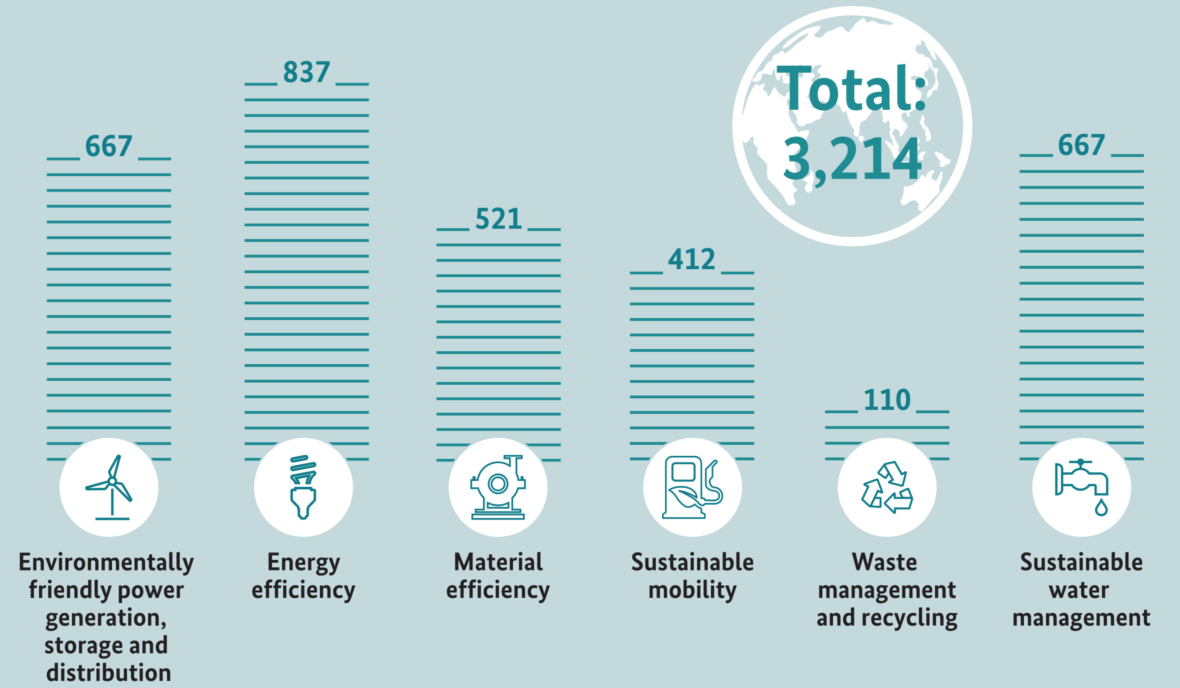
At a glance

The green tech industry is set to continue its expansion in the years ahead. The global market volume for environmental technology and resource efficiency is projected to increase from 3,214 billion euros in 2016 to 5,902 billion euros in 2025, equivalent to average annual growth of 6.9 percent. In Germany, the pace of expansion in this green branch of industry is even faster. In this country, the market volume will grow by an average of 8.8 percent a year through 2025, by which time the market volume will have reached 738 billion euros (up from 347 billion euros in 2016).

Globally, expansion is fastest in the lead market for sustainable mobility, for which average annual growth of 10.2 percent is forecast through 2025. The market segment for alternative drive technologies is largely responsible for this dynamic development, growing worldwide at an average annual rate of 29.2 percent in volume terms. In Germany, this market segment will experience 49 percent average annual growth between now and 2025, although expansion will also be conspicuously forceful in other areas of sustainable mobility. Five of the top ten technology lines – i.e. those with the fastest growth in Germany – belong to the lead market for sustainable mobility.

In total, German providers have a 14 percent share of the global market for environmental technology and resource efficiency. By comparison, Germany accounts for 4.6 percent of the world's economic output. Green tech's importance to Germany is reflected in this industry's share of gross domestic product (GDP). In 2016, environmental technology and resource efficiency contributed 15 percent to the country's economic output. Around 1.5 million people in Germany worked in the six green tech lead markets in the same year.

Figure 8: Global volume of lead markets for environmental technology and resource efficiency in 2016 (billion euros)



Source: Roland Berger (2017)

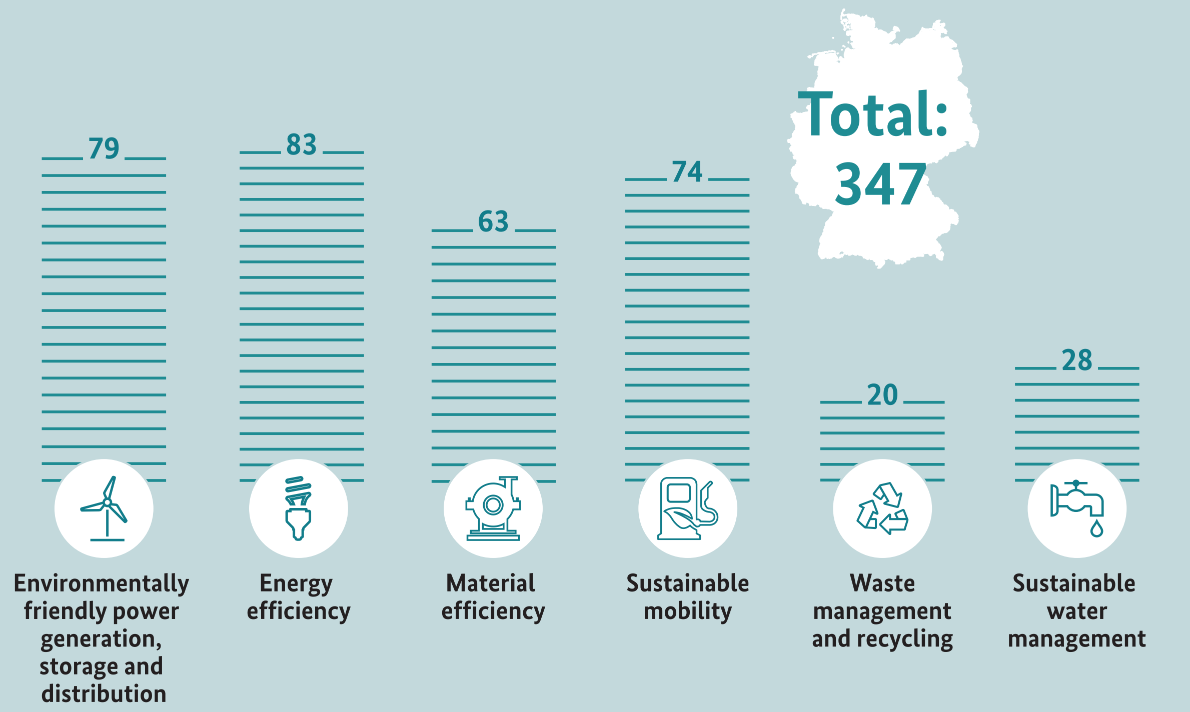
Developments on international markets and in Germany

The global market volume for environmental technology and resource efficiency exceeded the 3 trillion euros mark in 2016. Total revenue of 3,214 billion euros was generated across the six green tech lead markets (see Figure 8), continuing the expansive development of this green cross-sector industry. In 2013, the global market volume for environmental technology and resource efficiency came to 2,536 billion euros.[1] A volume of 837 billion euros in 2016 means that energy efficiency remains the largest of the green lead markets.

Germany: Energy efficiency the biggest lead market

The German market volume for environmental technology and resource efficiency stood at 347 billion euros in 2016. In this country, too, energy efficiency is the largest lead market in the green tech industry, with a market volume of 83 billion euros in 2016 (see Figure 9). The second-largest lead market – environmentally friendly power generation, storage and distribution – was worth 79 billion euros, while sustainable mobility tipped the scales at 74 billion euros. The listed sequence reflects Germany's pioneering position in the field of renewable energy and in the latter's integration in the power grid. The lead market for sustainable mobility feeds on growth stimulus from the automotive industry, a branch of industry that is traditionally very strong in Germany.

Figure 9: Volume of lead markets for environmental technology and resource efficiency in Germany in 2016 (billion euros)



Source: Roland Berger (2017)

1 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2015c), page 48.

Methodology: The basis for our market forecasts

The Roland Berger market model calculates the current volume and forecasts the future volume of each lead market. It takes as its starting point the various technology lines (products, processes and services) in environmental technology and resource efficiency. Based on a bottom-up approach, these technology lines are aggregated into the market segments that in turn form the six lead markets for green technology.

The underlying data for the technology lines comes from relevant market and sector studies. The data is derived from a business-as-usual scenario – a conservative analysis assuming that current valid environmental and regulatory laws and conditions will remain in force and then updating them in line with future market development forecasts.

The Roland Berger market model makes provision for the dynamic pace of development in this industry. To date, the calculation method has been reviewed prior to each issue of the GreenTech Atlas. Adjustments are made as and when necessary – for example if new market studies have been published that enable more accurate calculations, of if the classification of technologies has changed. Two examples illustrate the point: (1) In the energy-efficient lighting technology line, compact fluorescent lamps, once regarded as the green alternative to traditional light bulbs, have now been replaced by LEDs as the state of the art. As a result, the market model used for the 2018 GreenTech Atlas no longer includes the market volume for energy-saving lamps in its calculation of the green technology market. (2) In the market segment for efficiency gains in water usage, the market volume was hitherto calculated based on water management revenue, a putative investment rate and a payback period estimated in line with customary timelines in the industry. In this issue of the GreenTech Atlas, the historical investment volume was also used for comparison purposes. Payback periods were then adjusted in line with this data.

The Roland Berger market model deliberately analyzes technologies at the lowest level of aggregation. It also follows the general principle of analyzing only technologies, not applications or goods for consumption. This principle can be illustrated by taking an example from the electric drive systems technology line in the market segment for alternative drive technologies, a subset of the lead market for sustainable mobility. Above and beyond e-mobility in the passenger car segment, the market for electric drive systems also includes all the systems used in e-buses, e-bikes and other electrically powered modes of transportation (forklift trucks, motorcycles etc.). The market volume for e-cars is therefore not calculated in the technology line for electric drive systems, as this accumulates across many different technology lines (lightweight engineering technologies, electrochemical storage of energy, energy efficiency in automotive engineering, organic electronics etc.). This approach ensures that the market volume is not artificially bloated by cross-technology systems – such as e-cars – in which various technologies are used.

There are also technology lines that can constitute both a technology and a good for consumption, biomass being a case in point. Where this kind of technology line is examined within the framework of the market model, the market volume refers only to those technologies that are of relevance to green tech companies. The market volume in the technology line for biomass exploitation comprises generation technologies (biogas plants), means of transportation (special containers) and the use of biomass (such as firing chambers in cogeneration plants).

Some technology lines also have a service component. Services are structured and calculated on the basis of the study “Environmental technology services – Drivers of ecological modernization and employment”.[1]

The market model looks at the market size in 2016 and growth rates through 2025 in both the national and global markets for environmental technology and resource efficiency. The market shares of German green tech firms are derived from the global market volume. The international market volume reflects current usage of green products, processes and services around the globe and traces likely developments in demand for green tech. The level of demand on the green tech lead markets in Germany is then also outlined.

2 See Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2009b).

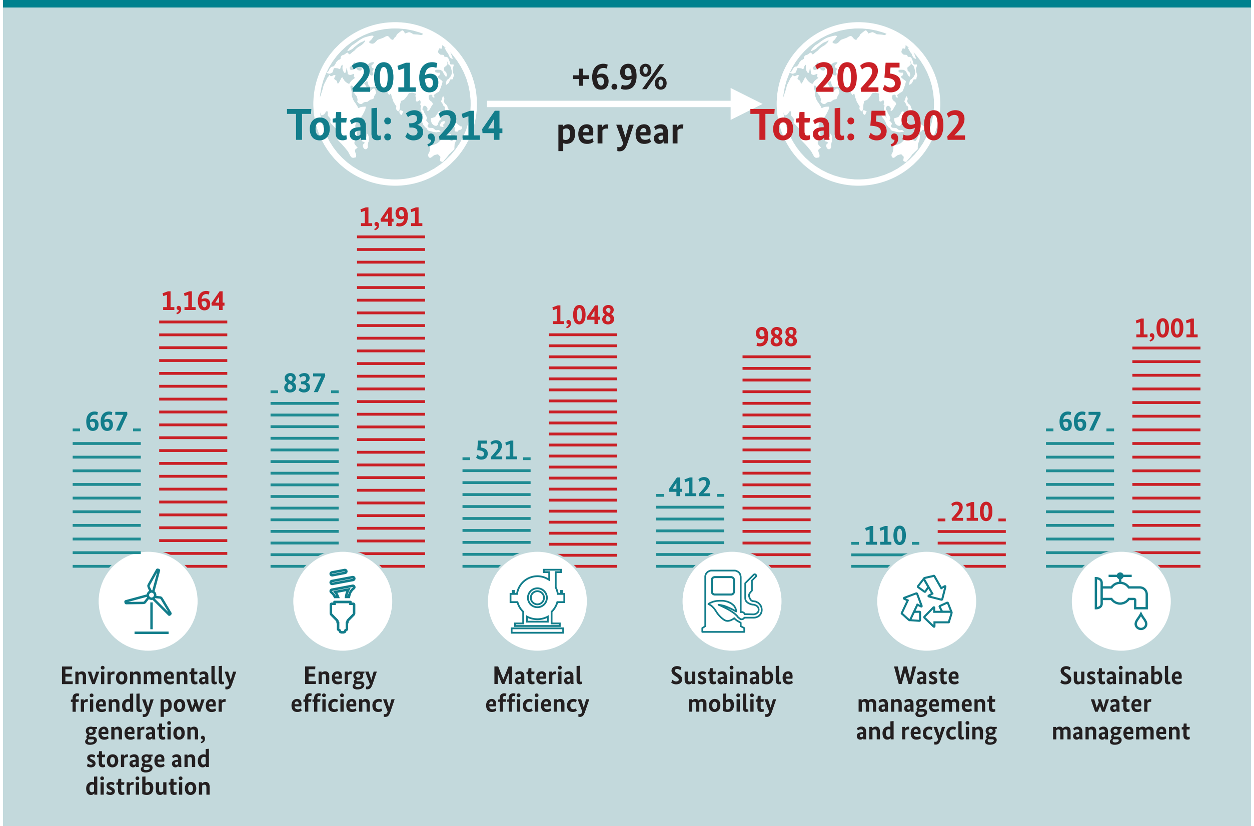
Demand for green products, processes and services will continue to increase in the years ahead. Backed by such fair winds, the green tech industry will proceed along its current growth trajectory both in Germany and in the international arena. The global market volume for environmental technology and resource efficiency will probably be 5,902 billion euros in 2025 (see Figure 10). In other words, this cross-sector industry will expand at an average annual rate of 6.9 percent in the period from 2016 through 2025.[3]

In Germany, environmental technology and resource efficiency will increase its market volume at an average annual rate of 8.8 percent through 2025 (see Figure 11). The rate of green tech growth in this country will thus slightly outpace the global figure. This forecast mirrors the importance of an environmental policy that is supported by the regulatory framework and that creates reliable guidelines for business investment decisions. At the same time, the expectations of customers in both the business-to-business and business-to-consumer segments will drive long-term demand for climate-friendly, environmentally compatible products and services.

It is a striking fact that demand for green technologies is rising faster in Germany than on a global scale. In the years ahead, strict environmental standards, the energy transition and companies' awareness of energy and material efficiency will fuel further growth in demand for green products, processes and services. Demand on the domestic market also creates opportunities for green tech companies based in Germany. Enjoying far closer proximity to their customers, they can collaborate with users to tailor the development of new technologies to individual needs. Cooperation on their home market is also conducive to systemic approaches within the green tech industry. Thanks to their expertise in system solutions and their wealth of technological knowledge, German-based environmental technology providers in particular can experience international success while also tapping large shares of the domestic market volume.

Within the overall market for environmental technology and resource efficiency, the individual lead markets are clearly growing at different rates on a global level. Expansion is fastest in the lead market for sustainable

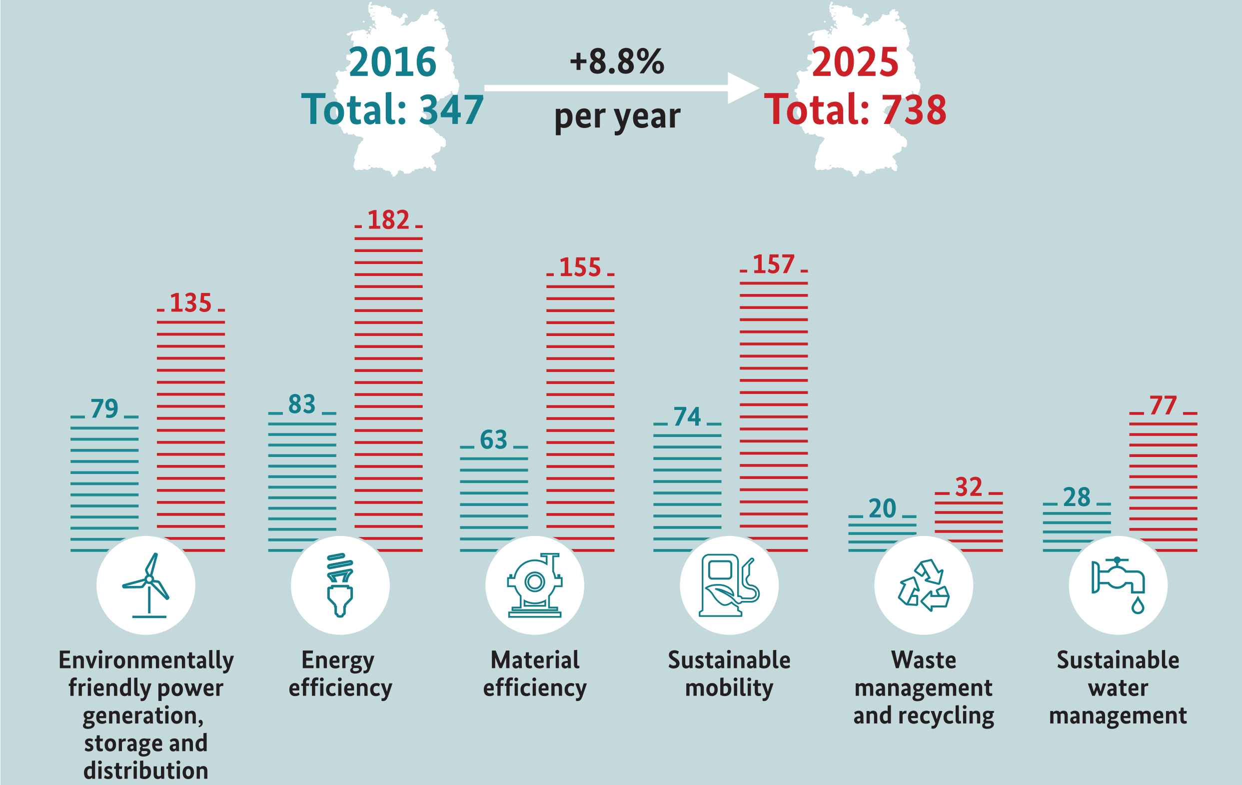
Figure 10: Development of the global market volume for environmental technology and resource efficiency, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

3 The figure 6.9 percent is calculated from the weighted average of average annual growth rates in the individual lead markets.

Figure 11: Development of the German market volume for environmental technology and resource efficiency, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

mobility, which grew at an average annual rate of 10.2 percent between 2016 and 2025 (see Figure 12). This rate of growth reflects worldwide endeavors to make the transport sector more climate-friendly and ecofriendly. Alternative drive technologies play a central role in decarbonizing the transport sector; and growth in this segment is putting wind in the sails of dynamic development across the entire lead market. This driver is itself backed by a shift in traffic policies in major markets, especially China. According to Chinese government plans, as many as five million electric cars – a market share of 5 to 10 percent – should be on the country's roads by 2020.[4]

Growth in the lead market for material efficiency is likewise outpacing the average rate of environmental technology and resource efficiency expansion. The projected average annual growth rate through 2025 is 9.1 percent. This expansion is being driven primarily by the renewable resources segment, which spans the technology lines for oils and fats from renewable resources, bioplastics and bioenergy (for heat and power generation). The market segment for cross-application technologies and methods is experiencing similarly dynamic development, especially in the organic electronics technology line. This line is becoming the new standard in many applications – witness the organic light-emitting diodes (OLEDs) used in smartphone displays, for example.

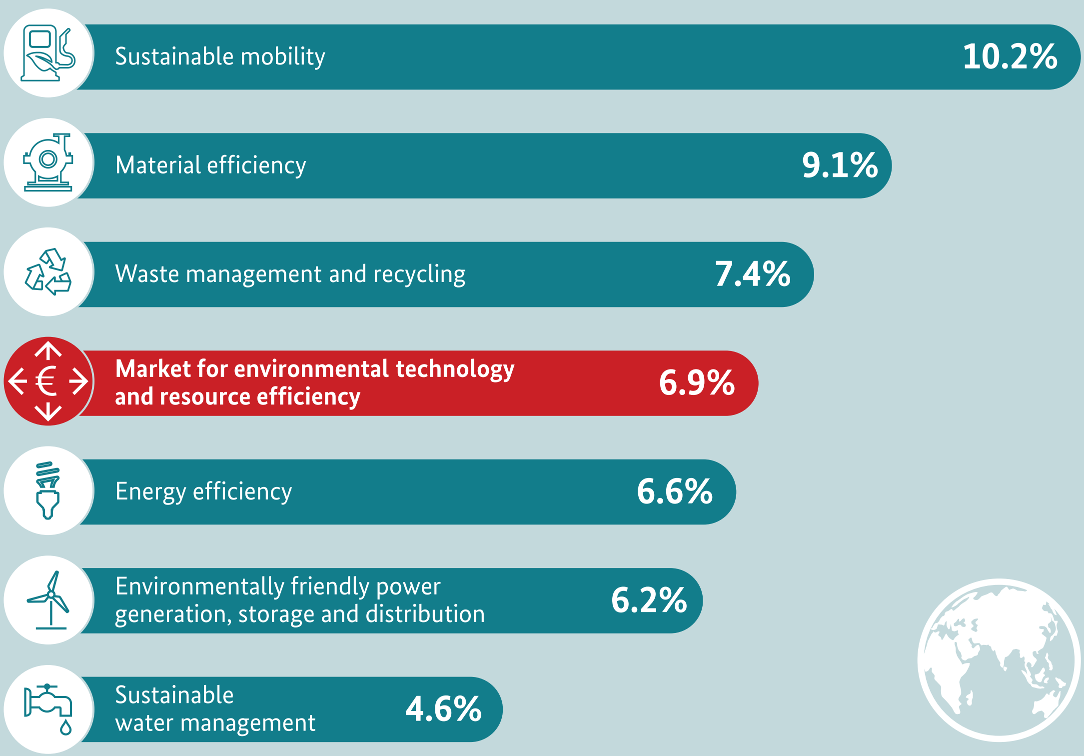
Within the wider sphere of environmental technology and resource efficiency, waste management and recycling is the lead market with the smallest volume. Emerging countries in particular nevertheless have a lot of ground to make up in the area of waste disposal. For example, the environmental policy goals laid out in China's 13th five-year plan feature a program of actions to control air, water and soil pollution that include improvements in the treatment of waste.[5] India, too, plans to tackle the subject of waste treatment and disposal with greater vigor, especially in relation to the recycling of scrapped electrical equipment, paper and plastics and the disposal of hazardous waste. Above all, India is looking to investment by private enterprise. Compared

4 See Becker, Joachim (2017).
5 See German Trade & Invest (2016).

to the green tech industry as a whole, growth in the lead market for waste management and recycling is slightly above average at 7.4 percent. This dynamism is injected first and foremost by the market segments for mechanical recycling and feedstock recycling.

Growth rates in the lead market for energy efficiency, environmentally friendly power generation, storage and distribution and the lead market for sustainable water management are lower than the average for the whole of the green tech industry. That, however, should in no way be taken to suggest that their significance is waning: These three lead markets are extremely important segments of the environmental technology and resource efficiency sector – segments that generate substantial revenues. The simple fact is that they are established markets with high revenue volumes and – in the case of most products and processes – an advanced level of maturity. This in turn causes pricing levels in these lead markets to tend to stagnate, in part due to economies of scale. The resultant savings are then reflected in comparatively lower growth rates, given that revenue is the basis on which lead market expansion is measured. The growth rates shown in Figure 12 are the overall figures for the individual lead markets. At the level of market segments and technology lines, however, even the "mature" lead markets have areas where technological changes are driving very dynamic development. One example is the 14.5 percent average annual growth that the energy-efficient lighting technology line will deliver through 2025 in the lead market for energy efficiency. Central to this development is rising demand for LEDs and halogen lamps as substitutes for traditional energy-saving lamps.

Figure 12: Global growth in lead markets compared to growth in environmental technology and resource efficiency overall, 2016 to 2025 (average annual change in percent)



Source: Roland Berger (2017)

Germany: Varying growth rates in the individual green tech lead markets

Analysis of the national situation again reveals variations in the pace of growth in the individual lead markets. Expansion is particularly forceful in the lead market for sustainable water management, where the average annual growth rate is 11.8 percent. The market segment for efficiency gains in water usage is the engine of growth here, delivering average annual expansion of 29.5 percent from 2016 through 2025. These numbers clearly show that the efficient management of water as a resource is playing an increasingly important role in private households, in agriculture and in industry, and that demand for suitable products, processes and services is on the rise.

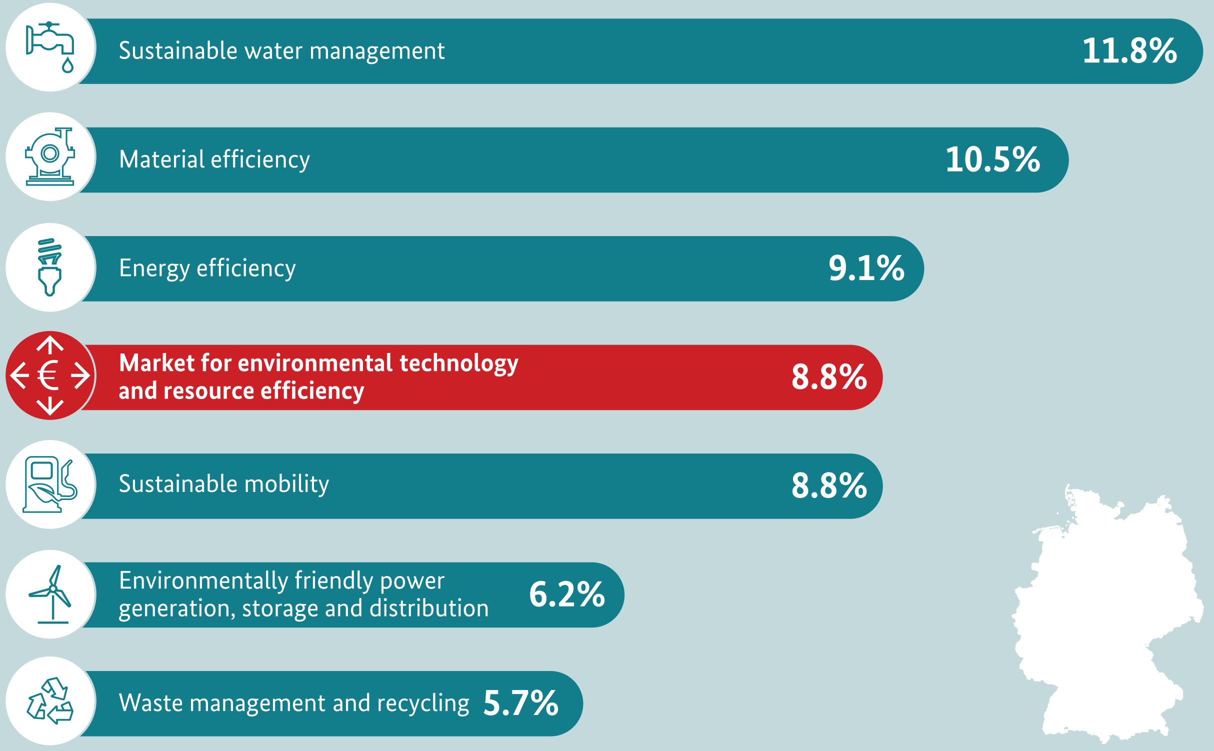
Above-average growth in the lead market for material efficiency (10.5 percent) is attributable above all to the market segment for cross-application technologies and methods. In this segment, the technology lines for organic electronics and nanotechnology are enjoying particularly forceful growth (at average annual rates of 17.4 and 20.0 percent respectively).

In Germany, the lead market for energy efficiency will expand at an average annual rate of 9.1 percent between 2016 and 2025. The impetus for this development comes primarily from the market segment for energy-efficient buildings.

Average annual growth of 8.8 percent in the lead market for sustainable mobility mirrors the circumstance that most of its segments serve mature markets. Closer analysis of this lead market reveals extremely dynamic development in the market segment for alternative drive technologies, which will grow at an average annual rate of 49.3 percent through 2025. This trend is being fueled above all by e-mobility. The technology line filling station infrastructure for alternative drive systems is experiencing similarly rapid growth at an average annual rate of 56.4 percent.

The lead market for environmentally friendly power generation, storage and distribution and the lead market for waste management and recycling are both expanding at slightly below the green tech industry average. Even so, both lead markets retain their importance within the wider framework of environmental technology and resource efficiency.

Figure 13: Growth in German lead markets compared to growth in environmental technology and resource efficiency overall, 2016 to 2025 (average annual change in percent)



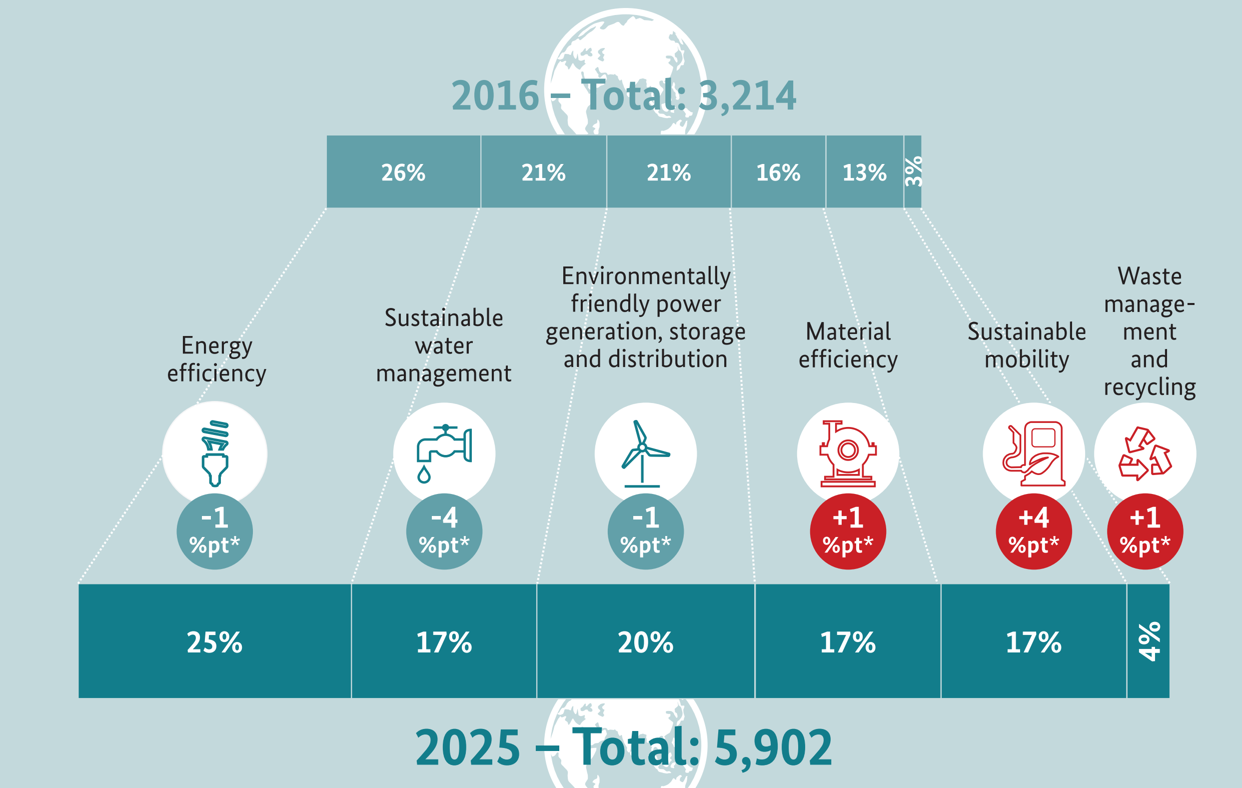
Source: Roland Berger (2017)

Figure 14 juxtaposes each lead market's share of the total volume for the global green tech industry in 2016 and 2025.

Worldwide, energy efficiency products, processes and services currently constitute the biggest lead market with a volume of 837 billion euros – 26 percent of the world's entire green tech industry. The lead market for environmentally friendly power generation, storage and distribution and the lead market for sustainable water management each have a 21 percent share (see Figure 14).

Given that the individual lead markets are growing at different rates, their relative shares of the global green tech market will naturally change between now and 2025. Energy efficiency will still maintain its position as the highest-volume lead market, probably accounting for 25 percent of the total environmental technology and resource efficiency volume. Sustainable mobility looks set to sharply increase its share of the overall green tech market, from 13 percent in 2016 to 17 percent in 2025.

Figure 14: Lead markets' shares of the total global market for environmental technology and resource efficiency in 2016 and 2025 (billion euros, percent)



* Percentage point
Source: Roland Berger (2017)

Technologies to mitigate climate change and adapt to the consequences of climate change

This section focuses on technologies across all the lead markets that contribute to keeping a cap on climate change. Analyzing this topic in isolation underscores the importance of products, processes and services that support strategies to adapt to the consequences of climate change and help reduce greenhouse gas emissions. Both mitigation technologies and goods and services that support adaptation to the consequences of climate change are spread across different lead markets for environmental technology and resource efficiency.

In the Paris Agreement,[6] the international community has committed itself under international law to the goal of keeping global warming to well below two degrees Celsius relative to preindustrial levels. Beyond this, countries will strive to limit the temperature increase to 1.5 degrees Celsius. The signatory states have further announced efforts to improve their ability to adapt to the negative consequences of climate change.

Climate change is present reality. The global average temperature is already one degree Celsius higher than preindustrial levels. The consequences are palpable: Droughts, floods and melting glaciers all show that climate change has long since been happening in the here and now. If the increase in greenhouse gases is not reined in, global warming could reach four degrees Celsius by the year 2100. On the other hand, if the rise in temperatures is kept below the two degrees Celsius ceiling, the world stands a good chance of averting at least the worst consequences of climate change. That, according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,[7] is still technologically and economically feasible. But climate change mitigation measures are needed to reach this goal.

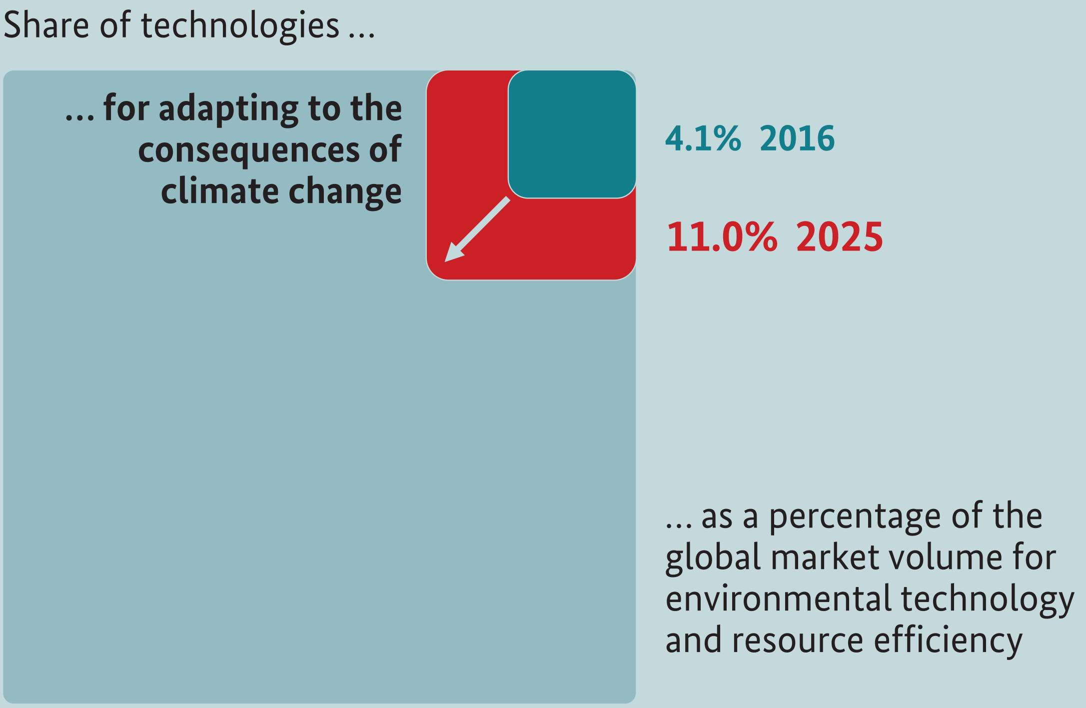
Climate change mitigation serves to limit future climate change:

> “*Mitigation is the effort to control the human sources of climate change and their cumulative impacts, notably the emission of greenhouse gases (GHGs) and other pollutants, such as black carbon particles, that also affect the planet's energy balance. Mitigation also includes efforts to enhance the processes that remove GHGs from the atmosphere, known as sinks. Because mitigation lowers the anticipated effects of climate change as well as the risks of extreme impacts, it is part of a broader policy strategy that includes adaptation to climate impacts.*”[8]

It follows that there is no contradiction in adapting to the consequences of climate change while at the same time striving to avoid or reduce greenhouse gas emissions. The two approaches are both integral components of climate policy: “Adaptation and mitigation [are] complementary strategies for reducing and managing the risks of climate change.”[9]

6 For a detailed account of the Paris Agreement, see Chapter 2, page 15f.
7 See Intergovernmental Panel on Climate Change (2014a).
8 See Intergovernmental Panel on Climate Change (2014b), page 114.
9 See Intergovernmental Panel on Climate Change (2014a), page 17.

Figure 15: Technologies for adapting to the consequences of climate change and reducing greenhouse gas emissions – Share of the global market for environmental technology and resource efficiency in 2016 and 2025



Source: Roland Berger (2017)

Analysis of all the lead markets for green technology reveals the huge predominance of technologies to reduce greenhouse gases. In 2016, products, processes and services to avoid and reduce emissions of greenhouse gases accounted for 96 percent of the global market volume for environmental technology and resource efficiency (see Figure 15). In the same year, however, only the market segment for climate-adapted infrastructure – with its technology lines storm, flood, heat and fire protection – represented the category "adapting to the consequences of climate change", alongside minor aspects of individual market segments and technology lines in the lead markets for sustainable water management (water production and treatment; the water distribution technology line; water efficiency technologies in agriculture) and waste management and recycling (the technology line for waste collection and transportation).

In 2025, technologies for adapting to the consequences of climate change will probably have an 11 percent share of the green tech market. The fact that the effects of global warming will be clearly felt by then will drive this surge of nearly seven percentage points compared to 2016. Some of these tangible effects will be the escalation of the water crisis in certain regions, the growing frequency of extreme weather events and their consequences (floods and droughts), and the advance of desertification. The goods and services needed to realize adaptation strategies are found mainly in the lead market for sustainable water management. Half of the global volume in the market segments for water production and treatment and for the water system can be attributed to climate adaptation technologies. For the technology line water efficiency technologies in agriculture, around three quarters of the market volume relates to these technologies.

The other lead markets also have a number of market segments and/or technology lines whose goods and services will, by 2025, be key in helping us adapt to the consequences of climate change. Examples include efficient heating, air-conditioning and ventilation systems, measurement and control instrumentation, biotechnology, renewable resources such as feedstock for the chemical industry, soil protection, the prevention of air pollution, nature and landscape conservation, groundwater protection, water conservation, waste collection and waste transportation.

Focus on global and national lead markets

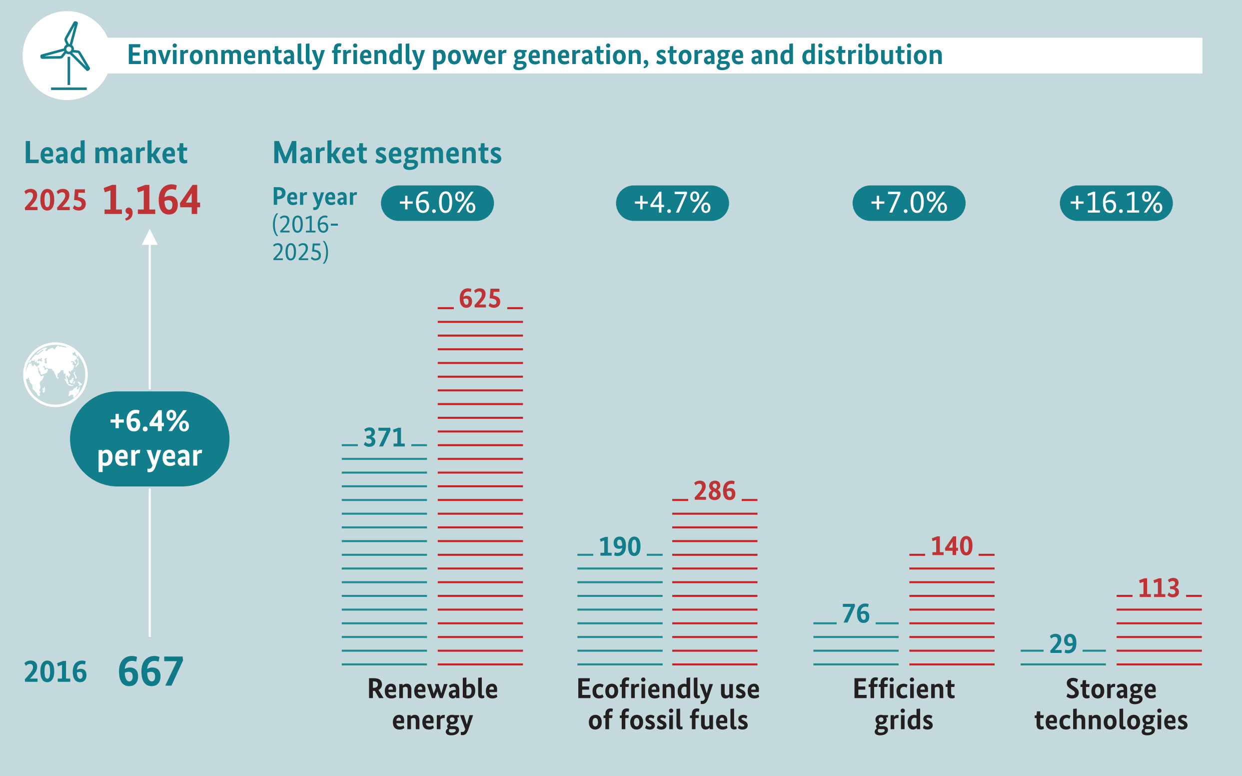
Environmentally friendly power generation, storage and distribution

Oil, gas and coal still easily dominate the global energy mix, with a combined share of 85 percent[10]. Burning these fossil fuels releases carbon dioxide into the atmosphere. Given that it is the source of roughly two thirds of global greenhouse gas emissions, the energy sector is thus of paramount importance to climate change mitigation. Transition in this sector is vital if the goals of the Paris Agreement are to be achieved. Steps in the right direction include the increased use of renewables, the environmentally friendly use of fossil fuels, energy storage and efficient grids. Action in these areas gives rise to those segments that make up the lead market for environmentally friendly power generation, storage and distribution.

In 2016, the global volume of this lead market stood at 667 billion euros. Average annual growth of 6.4 percent will boost this volume to 1,164 billion euros by 2025 (see Figure 16).

A detailed look at the market segment for renewable energy highlights the prominence of hydropower (see Figure 17). This technology line accounted for just

Figure 16: Development of the global lead market for environmentally friendly power generation, storage and distribution by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

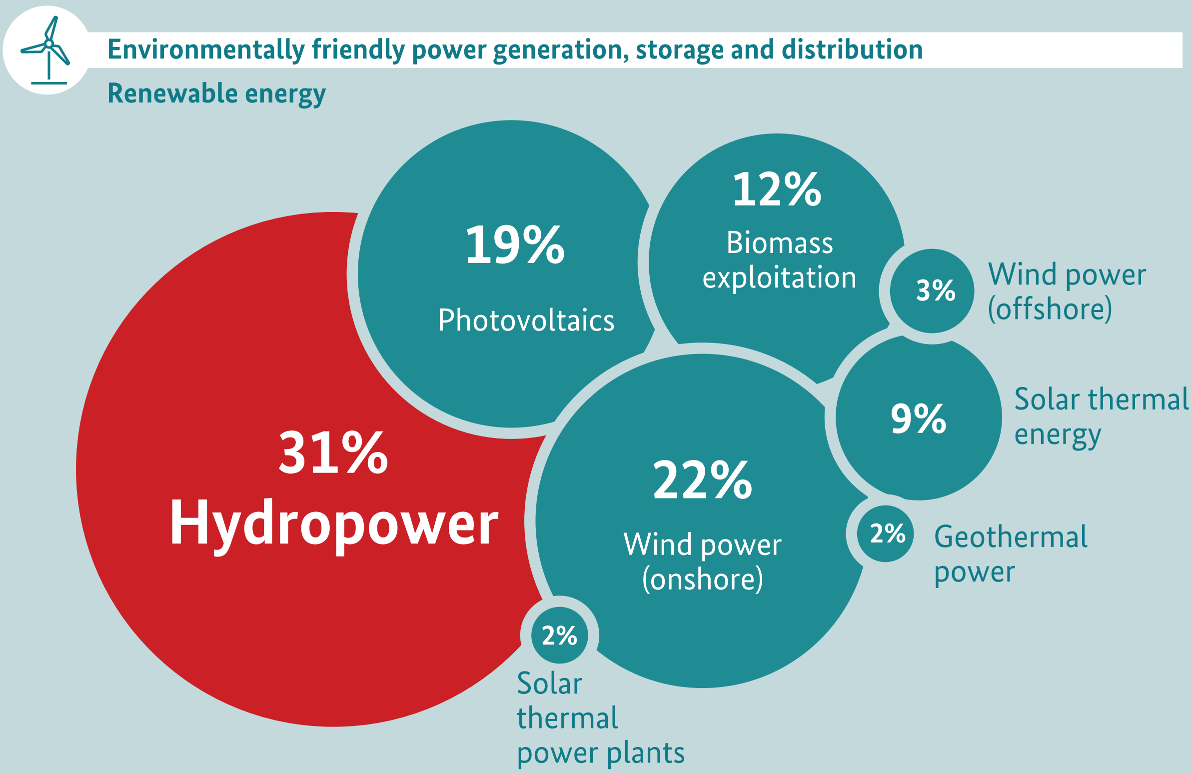
10 See BP Statistical Review of World Energy June 2017, page 9.

under a third of the global market volume in the renewable energy segment in 2016. However, hydropower is likely to stagnate at this level: Between 2016 and 2025, the market volume for this technology line is projected to edge up from 114 billion euros to 118 billion euros – equivalent to average annual growth of 0.4 percent. Solar and wind power have a global installed capacity of 790 gigawatts and are gaining an increasingly large share of the renewable energy mix. In 2016, their share of green power generation totaled 39 percent.[11] Photovoltaics made up 19 percent of the renewable energy market segment in 2016, while onshore wind power accounted for 22 percent of the segment's total revenue. Forecasts point to strong growth in both of these technology lines in the years ahead.[12] And our study concurs in this assessment: Worldwide, the photovoltaics technology line will expand by an average of 7.9 percent each year between 2016 and 2025. In the same period, onshore wind power will see average annual growth of 9 percent. Solar and wind power will thus increase their share of the renewable energy mix. In 2025, photovoltaics and wind power will together boast a 50 percent share of the global market volume in the renewable energy market segment.

In the market segment for the ecofriendly use of fossil fuels, gas and steam power plants and high-capacity power plants[13] are by far the dominant technology lines. Together they shared a global market volume of nearly 132 billion euros in 2016 – 72 percent of the total worldwide volume in this market segment. By 2025, this share will probably decline to 64 percent due to factors such as dynamic development in the cogeneration units technology line (whose annual growth will average 14.3 percent).

In the global lead market for environmentally friendly power generation, storage and distribution, the market segment for storage technologies will grow at an exceptionally dynamic average annual rate of 16.1 percent).

Figure 17: Individual technology lines' share of the global volume in the market segment for renewable energy in 2016 (percent)



Source: Roland Berger (2017)

11 See REN21 Renewable Energy Policy Network for the 21st Century (2017), page 21.

12 See Global Wind Energy Council (2017).

13 High-capacity power plants are coal-fired power plants with an efficiency level of over 45 percent. Traditional coal-fired power plants have an efficiency level of approximately 32 percent. High-capacity power plants are also known as "supercritical" or "ultra-supercritical" plants. Using high-temperature and high-pressure technology, steam is heated to a temperature above 374 degrees Celsius and raised to pressure above 221 bar. This makes it possible to achieve higher efficiency levels than in conventional power plants.

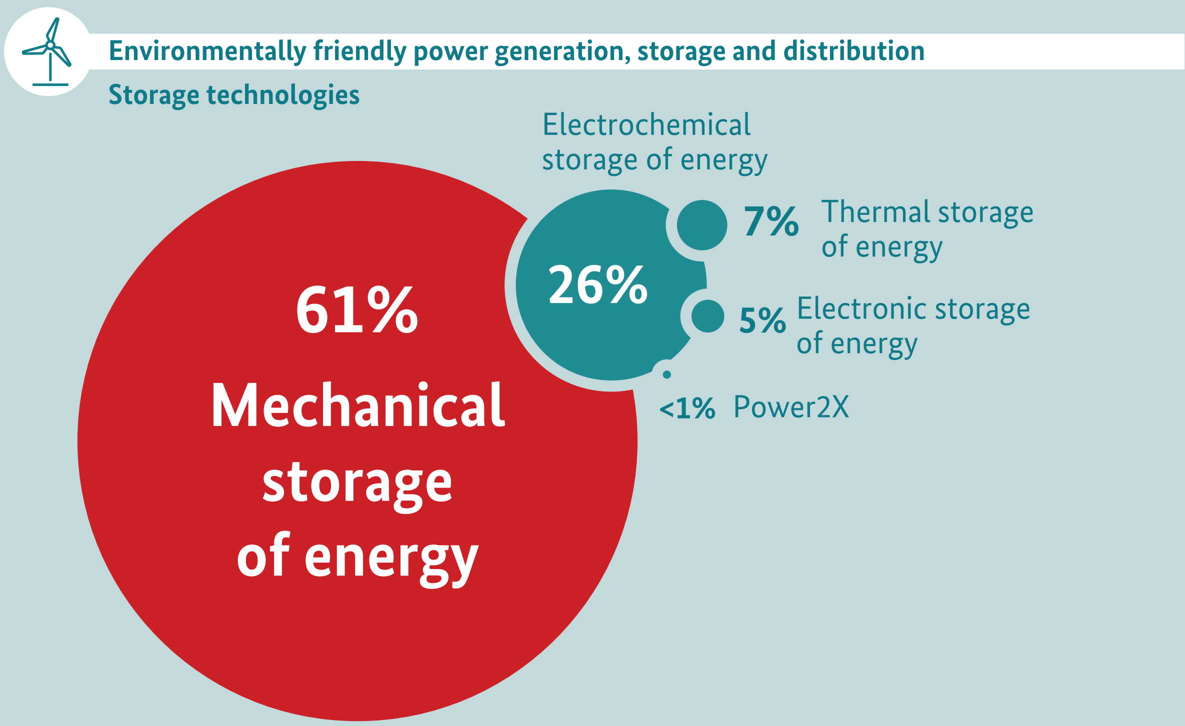
In the period from 2016 through 2025, the global volume for this market segment will therefore almost quadruple from 29 billion euros to 113 billion euros.

Closer analysis of the structure of the market segment for storage technologies reveals the dominance of the mechanical storage of energy (see Figure 18). This technology line accounted for nearly two thirds of the global market volume for storage technologies in 2016. Mechanical storage technologies include pumped storage hydropower plants, compressed air energy storage, lift storage power plants and flywheel energy storage. Pumped storage hydropower plants in particular make a major contribution to stabilizing the energy supply. They balance out fluctuations in the power grid – such as the rise in demand during peak periods – and serve as a last resort in the event of power plant shutdowns. Pumped storage hydropower plants have the ability to "black start", i.e. to start up without relying on external power sources.

Among the different storage technologies, the electrochemical storage technology line will experience particularly rapid development. With average annual growth of 23.1 percent, its global market volume will expand from 7.6 billion euros in 2016 to 49.4 billion euros in 2025. Electrochemical storage includes various types of batteries that essentially function as energy stores and energy converters: Discharge converts stored chemical energy to electrical energy by means of a reduction-oxidation (or redox) reaction. The electrical energy is then fed into consumers. Primary cells have to be disposed of after a one-off discharge. By contrast, secondary cells (lead, nickel-cadmium, nickel metal hydride, lithium-ion etc.) can be recharged and are therefore referred to as rechargeable batteries.

The main factor driving strong growth in electrochemical storage through 2025 is the dynamic development of battery storage systems. Applications in e-mobility (electric cars and e-bikes) and stationary

Figure 18: Individual technology lines' share of the global volume in the market for storage technologies in 2016 (percent)



Source: Roland Berger (2017)

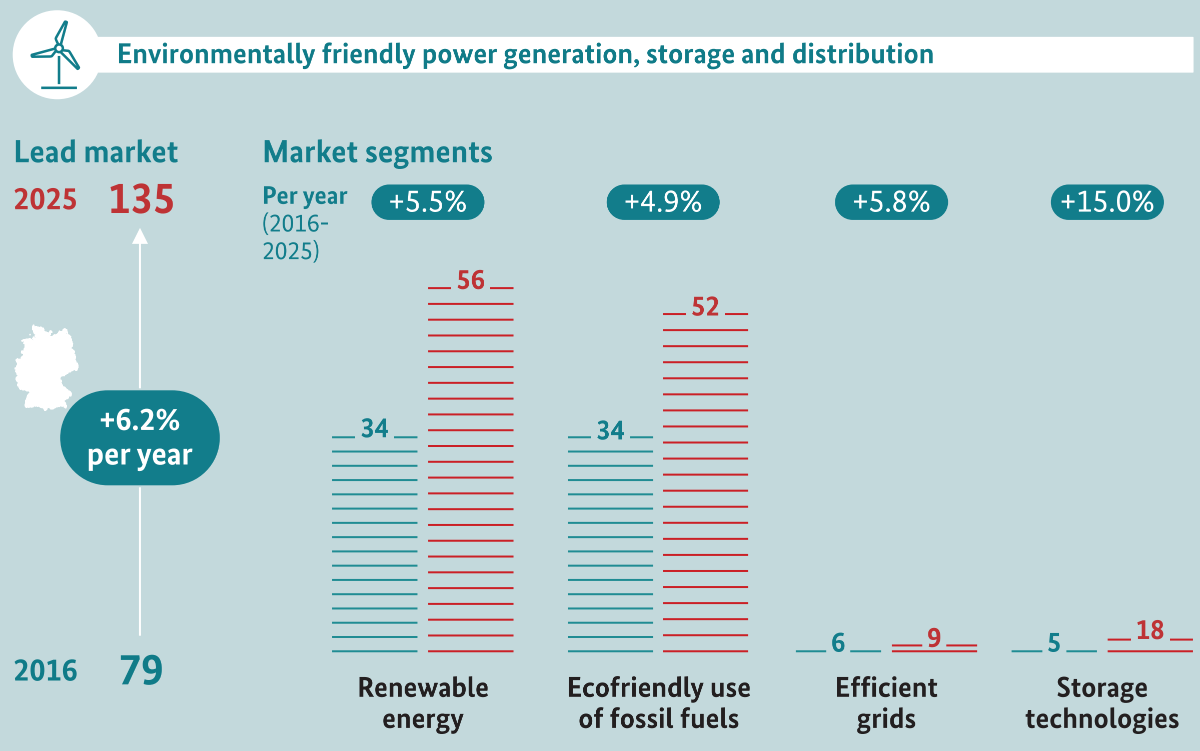
energy storage will make the main contributions to this expansion. From an economic perspective, combining stationary storage solutions with autonomous power generation from renewable sources is an extremely attractive proposition that can help stabilize the power grid.

The market segment for efficient grids recorded a global market volume of 76.3 billion euros in 2016 and is set to grow at an average annual rate of 7 percent through 2025. Accordingly, the worldwide volume for this market segment is projected to reach 140.4 billion euros in 2025.

Germany: The lead market for environmentally friendly power generation, storage and distribution

By and large, development in the German lead market for environmentally friendly power generation, storage and distribution takes its cue from the international trends. In Germany, this lead market will expand at an average annual rate of 6.2 percent between 2016 and 2025 (see Figure 19). Its volume will thus rise from 79 billion euros to 135 billion euros in this period. Storage technologies are experiencing the most dynamic development, growing by an average of 15 percent per year through 2025 – a remarkable rate of expansion by any standards.

Figure 19: Development of the lead market for environmentally friendly power generation, storage and distribution in Germany, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

Floating wind turbines

Around the globe, new wind turbines with a total capacity of 55 gigawatts were installed in 2016, bringing the world's total installed wind power capacity up to 487 gigawatts.[14] The majority of these turbines operate on land, however. Offshore wind turbines only managed a capacity of 14.4 gigawatts in the same year, but harbor huge potential.[15] Compared to good terrestrial wind power locations, the electricity yield from offshore wind turbines is as much as 40 percent higher. This is because the wind blows more strongly and more constantly at sea.

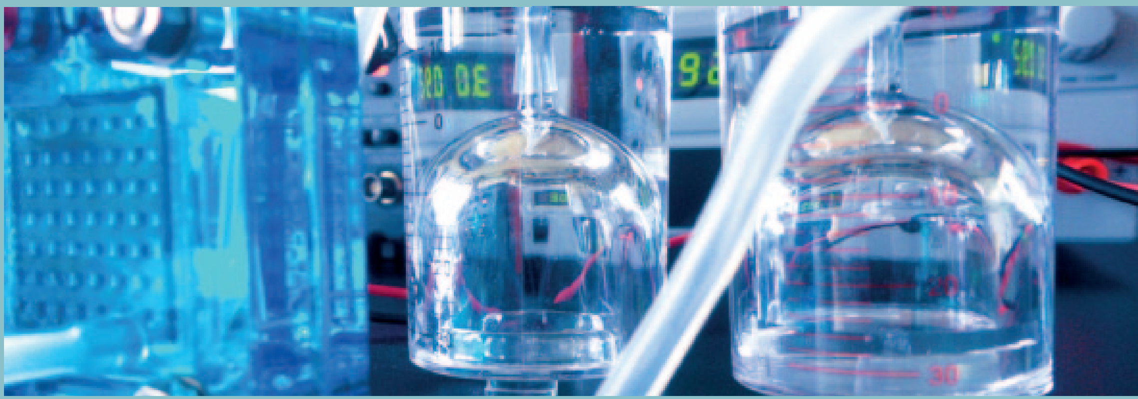
The downside is that building offshore wind turbines is expensive and technically very challenging. There are also ecological risks, such as intensive noise exposure when the foundations are rammed into place. To keep the towers, nacelles and rotors stable and make sure they do not buckle even in the most severe storms, the foundations have to go as far down as 40 meters into the seabed. The towers are then assembled on this base, requiring a water depth of at least 20 meters. At water depths in excess of 50 meters, it becomes technically very difficult – and economically non-viable – to lay firm foundations. Due to this restriction, the majority of marine areas and the high energy yields they promise are off limits to wind turbine construction – unless alternatives to firmly mounted bases can be used. Work is currently underway to develop floating wind turbines that would be suitable for water depths of several hundred meters. An array of design principles has been proposed for the floating structures:[16]

- Spar buoys – The floating structure is a spar-shaped buoy that stands upright in the water. The top of the spar is filled with air and the bottom contains ballast to ensure a low center of gravity. Like a tumbler toy, the floating structure always rights itself to a vertical position: It cannot fall over. Mooring lines attach the spar buoy to anchors on the seabed.
- Barges – The floating structure is a broad, flat float that drifts like an inflatable mattress on the water surface. When waves hit this air cushion and cause it to tip, it rights itself. Loose mooring lines attach the floating structure to anchors on the seabed.
- Semisubmersibles – With this technology, the whole of the relatively broad buoyancy element is under the surface of the water. Since the intensity of wave motion diminishes as depth increases, semisubmersibles lie more steadily in the water. The wind turbine stands on cylindrical pillars mounted on top of the floating structure.
- Tension leg platforms (TLPs) – The floating structure lies under water and is fitted with cables that moor it to anchors on the seabed. Its buoyancy keeps the tension in the cables (legs) constant and keeps the structure stable.

A floating wind turbine with a tension leg platform is currently being tested off the Darss peninsula on Germany's Baltic coast. The turbine has a capacity of 2.3 megawatts, has a tower standing more than 100 meters tall and was developed by the GICON Group (Dresden) and Edelstahl- und Umwelttechnik Stralsund GmbH.[17] What is currently the largest floating offshore wind farm in the world went into service off the east coast of Scotland in October 2017. Statoil built "Hywind Scotland" about 25 kilometers off Peterhead at a water depth of 95 to 120 meters. The farm comprises five wind turbines with capacities of 6 megawatts each and meets the electricity needs of around 20,000 households. The spar buoys are 80 meters long.[18]

14 See REN21 Renewable Policy Network for the 21st century (2017), page 88.
15 Ibid, page 89.
16 See Eder, Stephan (2016).
17 See eLife (2017).
18 See Statoil (2018).

Power to liquid



E-mobility plays a key role in efforts to design a more environmentally and climate-friendly transport sector. Yet not all mobility needs can be met with electric drive systems. Accordingly, demand exists for liquid fuels that constitute an alternative to environmentally harmful fuels such as diesel and kerosene. Power to liquid (PTL) – producing synthetic fuels from a mix of electric power from renewable sources and water – is one very pro-mising approach.

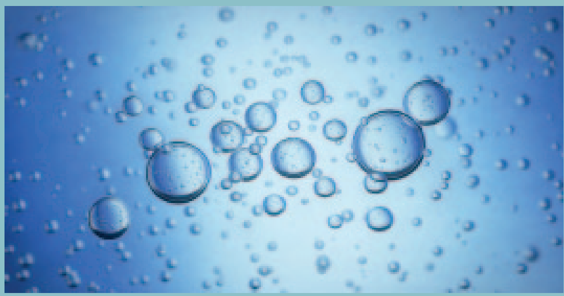
What is known as excess power can be tapped for the first step, which is using electrolysis to split water into hydrogen and oxygen. Excess power is generated when a particularly large volume of electricity is produced by fluctuating energy sources such as wind and solar power but cannot be fed into the grid. The second step is to convert carbon dioxi-de to carbon monoxide, before the Fischer-Tropsch method is used to synthesize liquid hydrocarbons (in this case: fuels).

The power-to-liquid method is expected to play a very important part in achieving the goal of a low-carbon and, in the longer term, zero-carbon power supply. It allows fuel to be generated from renewable sources without the need to cultivate biomass for energy applications. Since the latter practice competes with food cultivation, the jury is still out on whether biomass as an alternative fuel variant is really a good thing.[19]

Using solar power to capture carbon dioxide from the air and produce synthetic fuels, the first compact power-to-liquid plant went into service in November 2016. In this SOLETAIR project, INERATEC, a spin-off from the Karlsruhe Institute of Technology (KIT) is collaborating with Finnish partners. The pilot plant is situated on the campus of Finland’s Lappeenranta University of Technology. It comprises three components: a direct air capture unit, an electrolysis unit that uses solar power to produce hydrogen, and a micro-structured chemical reactor to synthesize hydrogen and carbon dioxide into liquid fuels (gasoline, diesel and kerosene). The reactor was developed at KIT and refined into a market-ready pilot plant by INERATEC.[20]

19 See Umweltbundesamt (2017c).
20 See Karlsruher Institut für Technologie (2016).

Hydrogen – a highly versatile element



There are those who see water as the oil or coal of tomorrow. Such euphoric future visions testify to the great expectations that are bound up with the use of hydrogen in energy systems going forward.

The most common chemical element in the universe, hydrogen exists in water and most organic compounds. While experimenting on mass conservation, French chemist Antoine Lavoisier discovered the gas in 1787, calling it "inflammable air".

In the Earth's atmosphere, hydrogen exists almost exclusively in chemical compounds, mainly in the form of water. There are a number of ways to produce hydrogen: steam reforming, partial oxidation, autothermal reforming, gas treatment, electrolysis of water, biomass, the Kvaerner process, thermochemical cycles and so on. Worldwide, more than 600 billion cubic meters – roughly 30 million tonnes – of hydrogen are produced for industrial and technical applications.[21]

In the context of the energy transition, the focus is on producing hydrogen with the aid of renewable energy sources such as the sun and the wind. Using green electricity, water is split into oxygen (O_2) and hydrogen (H_2) by means of electrolysis. This power-to-gas process (also known as P2G or PtG) can use excess power: the power left over when a particularly large volume of green electricity is produced but cannot be fed into the grid. Hydrogen serves as a storage solution. It can later be reconverted to electricity using gas turbines or used as fuel for fuel cell vehicles or heating purposes. Thanks to this wide range of applications, power to gas could become a key basic technology for distributed, low-carbon energy systems.

Fuel cells play a pivotal role in the various potential applications for hydrogen. In their capacity as galvanic elements, they convert the chemical reaction energy from the continual input of fuel and an oxidizing agent into electrical energy. Fuel cells can be deployed for both mobile and stationary applications.

For mobile use in fuel cell vehicles, the electricity needed to drive the vehicle is generated on board: Hydrogen (H_2) is split into protons and electrons in the fuel cell. The chemical energy released by this process is converted to the electrical energy that powers the engine. Water is a by-product from this reaction.

Many large automotive manufacturers have already developed hydrogen-powered prototypes or pre-series models. The Clean Energy Partnership[22] is overseeing a number of research and demonstration projects to try out hydrogen technology under near-real-world conditions in the transport sector. The primary focus here is on the numerous interfaces between vehicle technology, hydrogen production and filling station infrastructures.

Several examples from the project portfolio show that hydrogen mobility goes far beyond usage in passenger cars alone. Stuttgart streetcar operator Stuttgarter Strassenbahnen AG (SSB) has already trialed hydrogen-powered buses. The project – named S-Presso – tested four fuel cell/hydrogen hybrid buses built by Mercedes-Benz and deployed on two routes. Besides handling the procurement and testing of the 12-meter long buses, the four-year project also examined the requirements for a suitable depot and the qualifications needed by staff.[23]

21 See CHEMIE.DE Information Service GmbH (2017).

22 Founded in 2002 as a joint initiative of politics and industry under the lead of the German Federal Ministry of Transport, the Clean Energy Partnership (CEP) aims to test the suitability of hydrogen as an everyday fuel. Since 2008, the CEP has been a beacon project of the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP), implemented by the National Organization for Hydrogen and Fuel-Cell Technology (NOW). Its 20 industry partners (Air Liquide, BMW, Bohlen & Doyen, Daimler, EnBW, Ford, GM/Opel, H2 Mobility, Hamburger Hochbahn, Honda, Hyundai, Linde, Shell, Siemens, Stuttgart streetcar operator SSB, Total, Toyota, OMV, Volkswagen and Westfalen) work together with the aim of tearing down obstacles to the market launch of hydrogen-powered vehicles. See Clean Energy Partnership (2017).

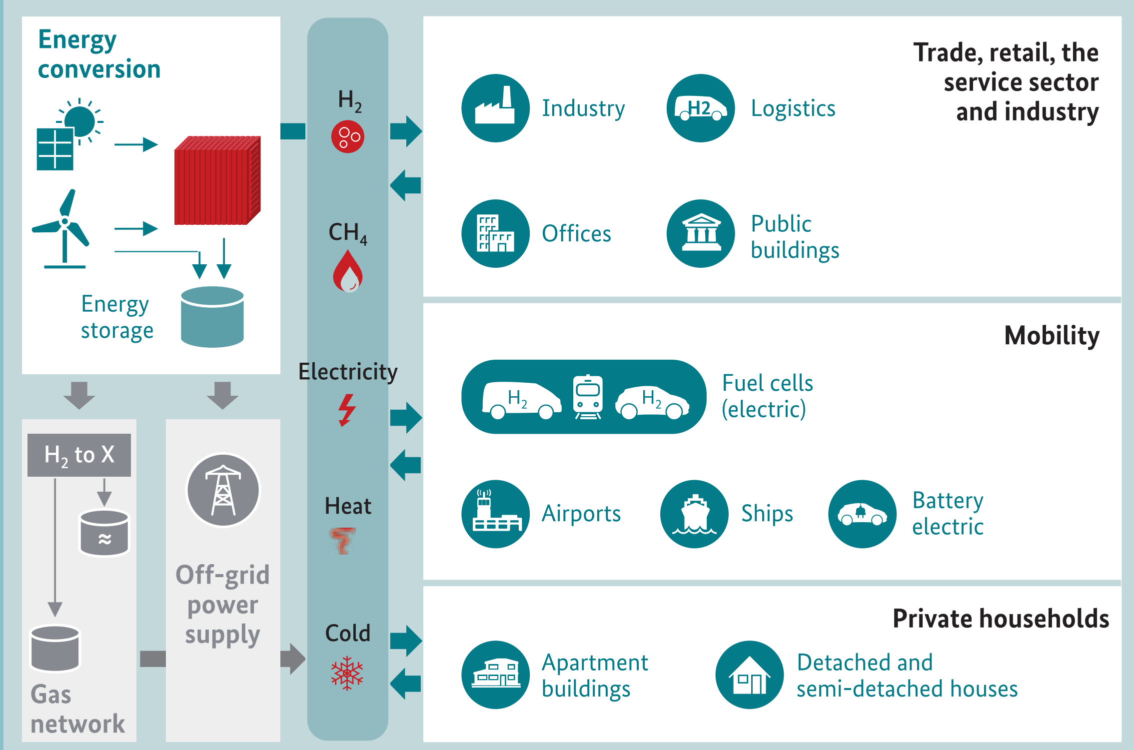
23 See Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017a).

For eighteen months, the RiverCell project has applied itself to developing a hybrid energy and drive system as an alternative to diesel engines for vessels that navigate inland waterways. Combining fuel cells with innovative engine technology, photovoltaics, heat recovery and energy storage in the form of batteries, an end-to-end electrical and thermal power supply was designed to this end. The project centered on the optimization of fuel cells for waterborne vessel applications.[24]

Fuel cells are also being tested in the context of intralogistics. At the Daimler factory in Düsseldorf, two forklift trucks powered by hydrogen fuel cells have been tested for two years.[25]

In system solutions for distributed power supplies, stationary fuel cells play an important part in supplying heat and producing electricity in buildings. Fuel cell heating devices can be deployed as cogeneration units in detached houses and apartment buildings. The units extract hydrogen from gas and use an electrochemical reaction to convert it to power and heat. Two advantages of this distributed power generation process are very low emissions and high efficiency levels. The Callux demonstration project tested the use of fuel cells to supply power for home use. The players involved claim that the seven-year real-world test prompted the broad market launch of appliances from a variety of manufacturers.[26]

Figure 20: Areas of application for hydrogen



Source: Roland Berger (2017)

24 See Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017b).
25 See Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017c).
26 Callux was a beacon project of the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP). The project, which ran from 2012-2015 with a budget of 86 million euros, involved the power utilities EnBW, E.ON Ruhrgas, EWE, MVV Energie and VNG Verbundnetz Gas and the appliance manufacturers Baxi Innotech, Hexis and Vaillant. The Center for Solar Energy and Hydrogen Research (ZSW) coordinated the project. See Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017d).

Leonardo and Leonardo II are two projects that are likewise working on fuel cell heating systems. Viessmann and Hexis are working together to develop a fuel cell heating system to expand the existing portfolio of fuel cell-based micro-cogeneration systems. One central aim is to cut the investment and running costs associated with models for volume production. The technological centerpiece of the new fuel cell heating system is a brand-new high-temperature technology known as solid oxide fuel cell (SOFC) technology.[27]

Energy efficiency

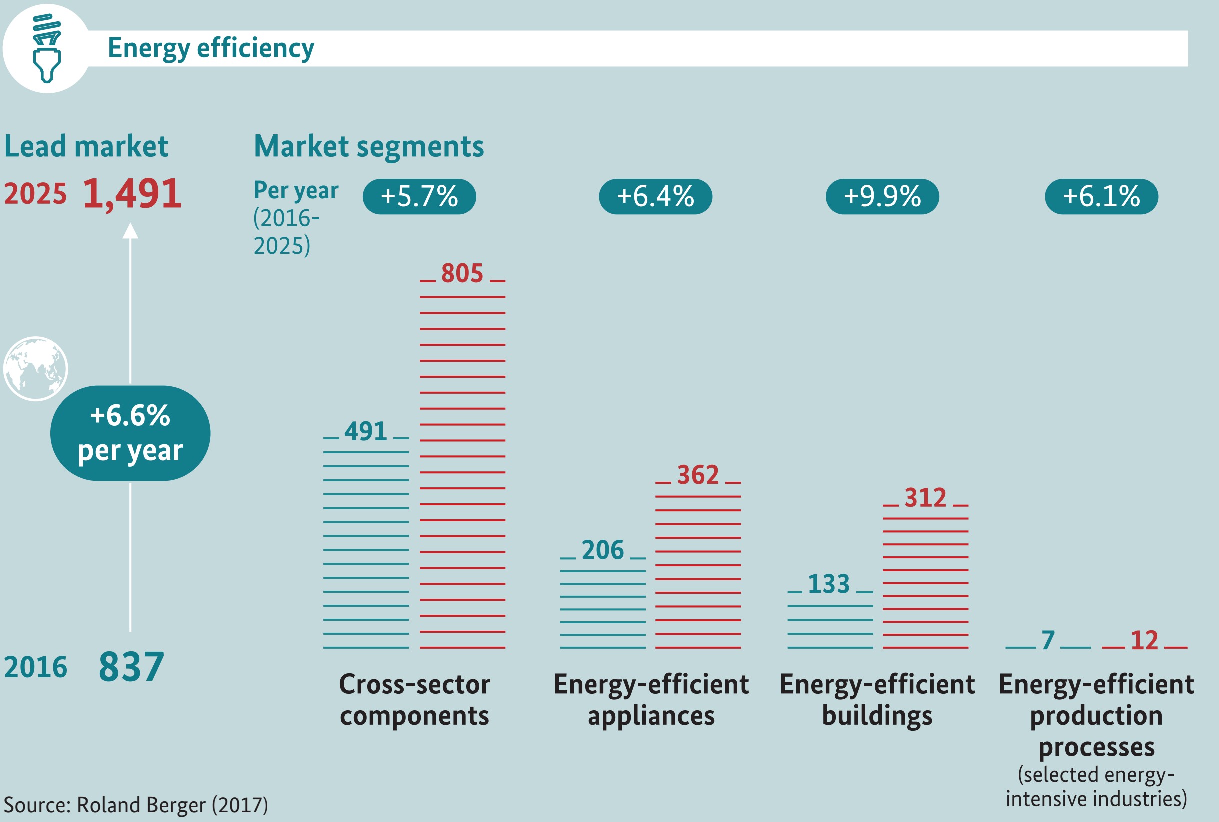
Improving energy efficiency is seen as another key way – along with stepping up the use of renewable energy – to rein in the consumption of energy resources and thus reduce the pollution and greenhouse gas emissions caused by the energy sector. Between 2016 and 2025, the global volume of the lead market for energy efficiency will increase from 837 billion euros to 1,491 billion euros, which works out at average annual growth of 6.6 percent (see Figure 21). The individual segments of this lead market are growing at varying rates. Cross-sector components were the largest market segment in 2016 with a global volume of 491 billion euros. However, given the high level of market maturity for products, processes and services in this segment, its average annual growth rate of 5.7 percent is lower than that of the other segments in the lead market for energy efficiency. Average annual growth of 9.9 percent singles out energy-efficient buildings as the market segment with the fastest rate of expansion.

Detailed analysis of the market segments and their technology lines paints a varied picture of the lead market for energy efficiency. In the market segment for cross-sector components, a global market volume of 165.6 billion euros puts measurement and control instrumentation out in front as the biggest technology line (see Figure 22). This line plays an essential role as the basis for resource-efficient production processes. Average annual growth of 3.9 percent should give measurement and control instrumentation a global market volume of 234.4 billion euros in 2025.

In 2016, electric drive systems had a global market volume of 125.6 billion euros and were the second-largest technology line in the market segment for cross-sector components. This technology line will see its global market volume rise to 260.2 billion euros in 2025, growing at an average annual rate of 8.4 percent from 2016 through 2025. Key drivers of this growth trajectory is the universal suitability of electric motors and the continuous improvements being made in their efficiency. Electric drive systems possess huge potential to reduce greenhouse gas emissions. Between now and 2020, the use of efficient industrial motors could save 27 billion kilowatt-hours of electricity – equivalent to slashing CO_2 emissions by 16 million tonnes.[28] Advances in the energy efficiency of electric drive systems have for years thus been an important element in the EU's efforts toward standardization. The Ecodesign Directive came into force in 2011, stipulating that all new motors must comply with efficiency class IE2 as a minimum requirement. In 2015, phase two of the Ecodesign Directive prescribed compliance with efficiency class IE3 for electric motors that run off mains power supply systems and have a rated output of between 7.5 and 375 kilowatts. Since January 2017, this rule has been further expanded to include the 0.75 to 7.5 kilowatt output range.[29] In the USA, Canada, South Korea and China, standards corresponding to efficiency classes IE2 or IE3 were introduced in advance of the European directive.

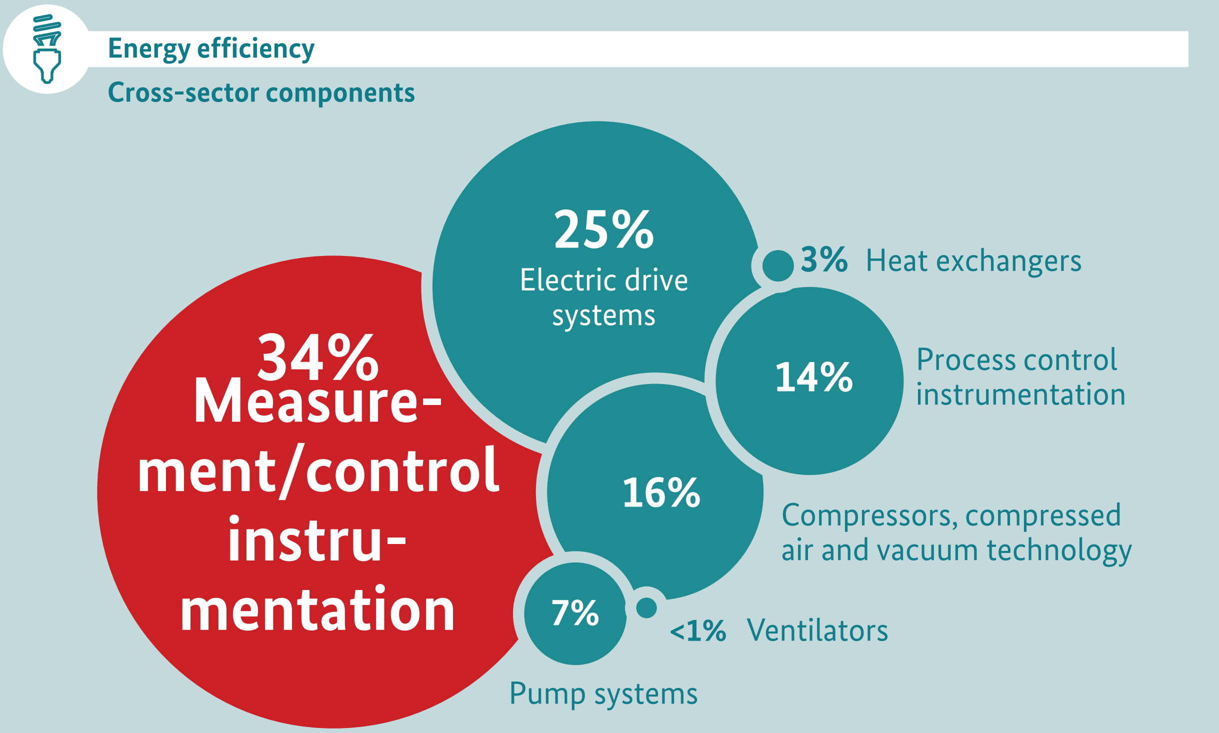
27 See Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017e).
28 See Grupp, Michael (2016).
29 These provisions do not apply to legacy systems, which remain bound by the rules that were in place when they were commissioned.

Figure 21: Volume development in the global lead market for energy efficiency by market segment, 2016 to 2025 (billion euros, average annual change in percent)



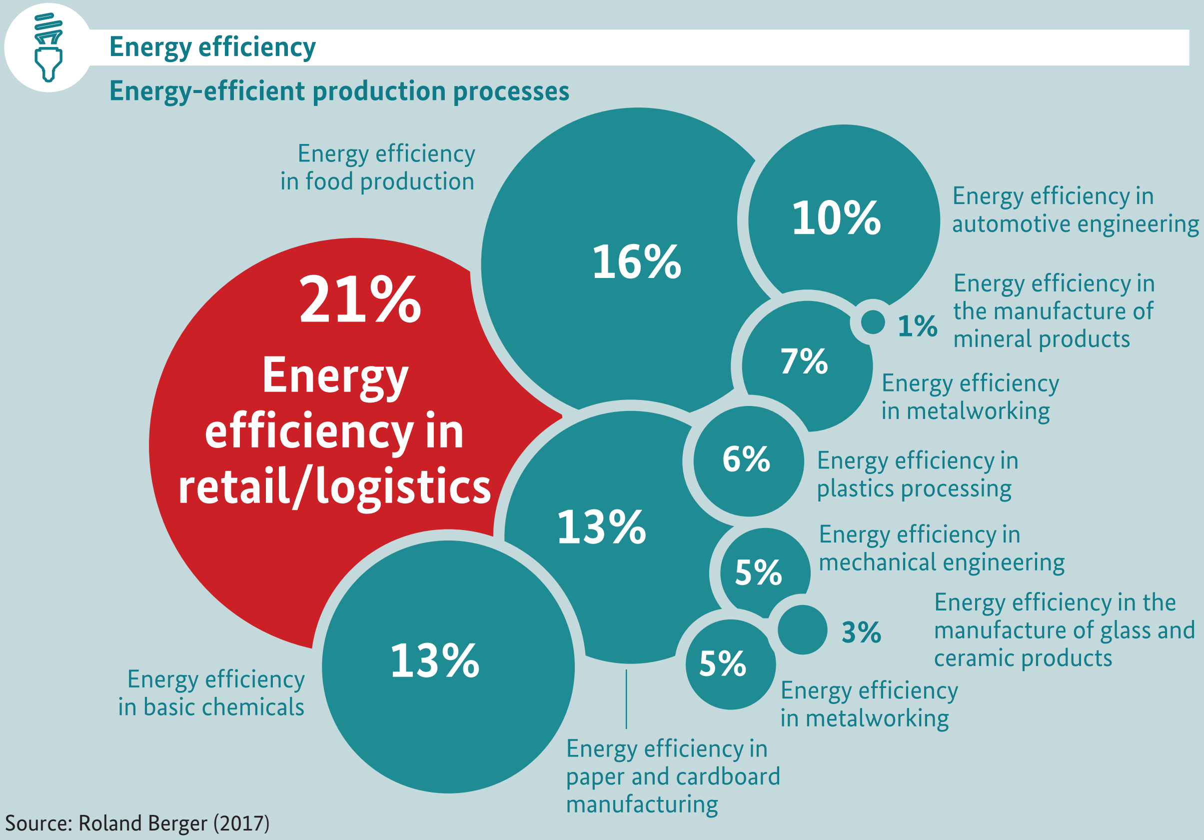
Source: Roland Berger (2017)

Figure 22: Individual technology lines' share of the global market volume in the market segment for cross-sector components in 2016 (in percent)



Source: Roland Berger (2017)

Figure 23: Individual technology lines' share of the global market volume in the market segment for energy-efficient production processes in 2016 (in percent)



Source: Roland Berger (2017)

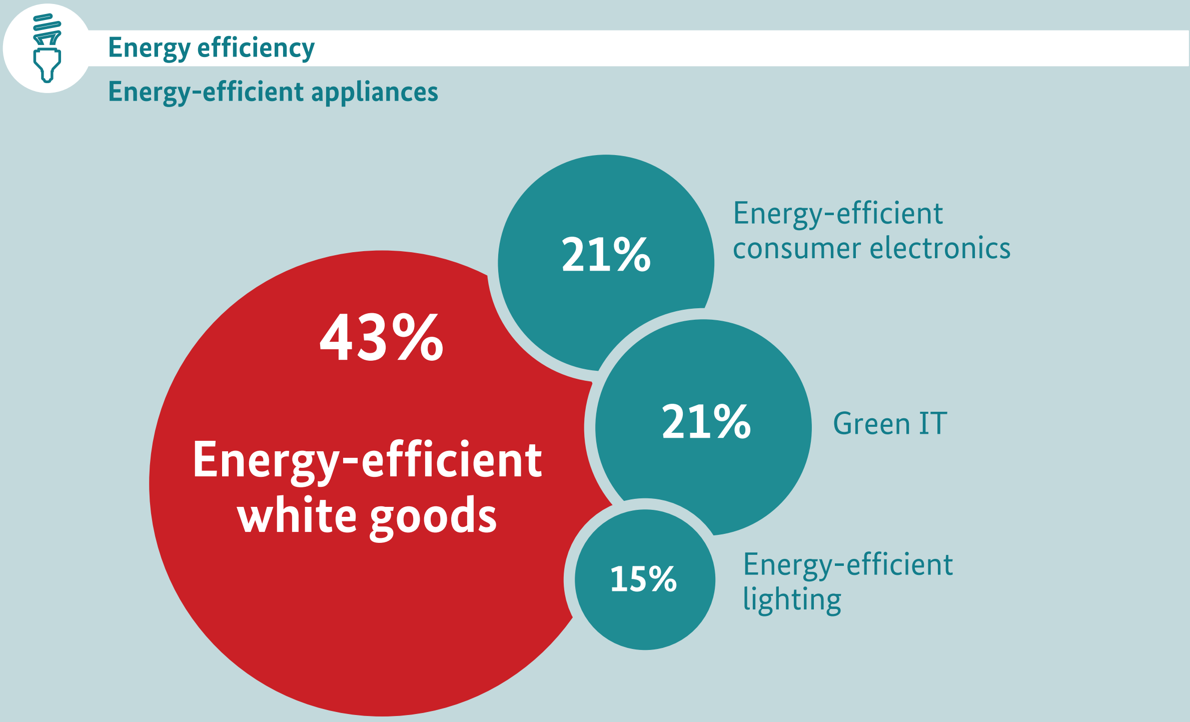
As shown in Figure 23, the market segment for energy-efficient production processes is highly fragmented, although isolated technology lines do have a substantial size. For example, the technology line for energy efficiency in retail/logistics accounted for over a fifth of the global market volume in this market segment in 2016. Energy-saving production processes also play an important role in other energy-intensive sectors, such as basic chemicals, automotive engineering and paper and cardboard manufacturing. In 2016, efficiency technologies for these industries together accounted for more than a third of the global market volume for energy-efficient production processes.

In 2016, the technology line for energy-efficient white goods (household appliances) was worth 88 billion euros, giving it easily the largest share of the global volume in the energy-efficient appliances market segment (see Figure 24). This line will grow at an average annual rate of 3.7 percent between 2016 and 2025, reaching a global market volume of 122.4 billion euros in 2025. Substantially stronger annual expansion of 14.5 percent will be delivered by energy-efficient lighting. This technology line will thus see its global market volume jump from 28 billion euros in 2016 to 109 billion euros in 2025. LED lamps' increasing market penetration are the mainstay of this dynamic development. More and more of these lamps are now being deployed in production facilities and municipal contexts.

The market segment for energy-efficient buildings recorded a global market volume of 133 billion technology in 2016. Average annual growth of 9.9 percent will see this volume rise to a projected 312 billion technology by 2025. In terms of market volume, heating, air-conditioning and ventilation (HVAC) systems is the most important technology line in this segment, with a volume of 59.3 billion technology in 2016 (see Figure 25). Its prominent position is rooted in considerable energy-saving potential combined with relatively short payback periods. Rapid development with average annual growth of 9.2 percent will continue through 2025, by which time this technology line will have a global market volume of 131 billion technology.

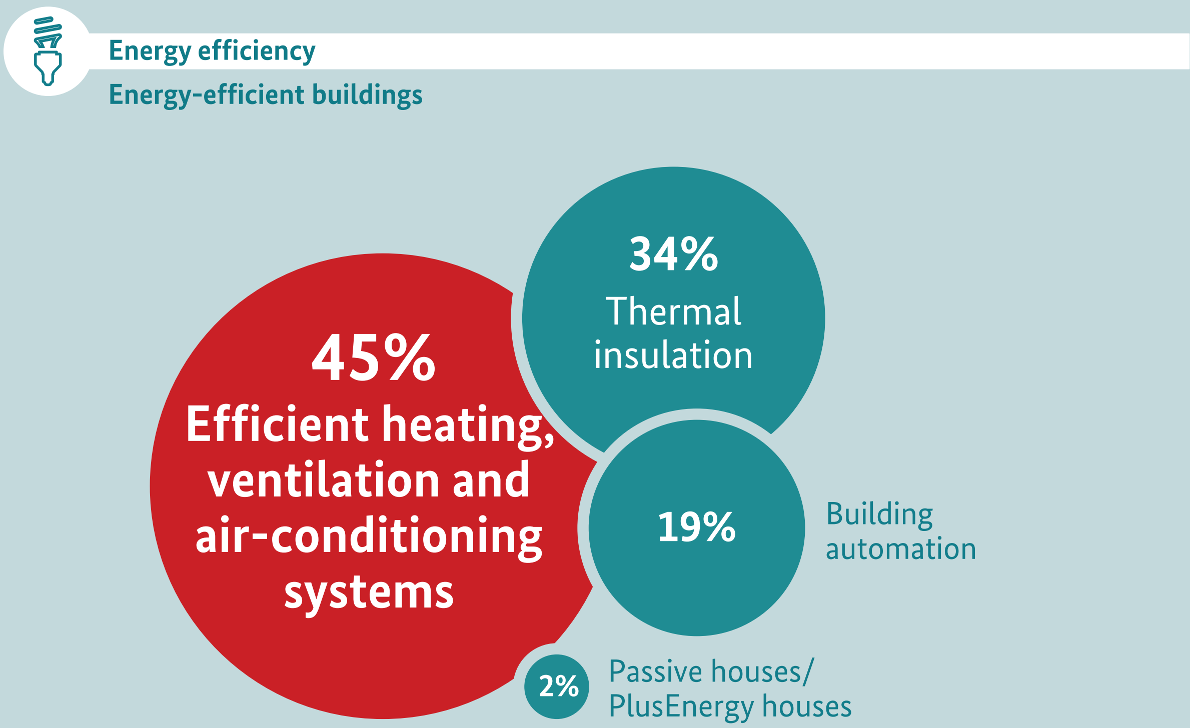
The technology line for passive houses and EnergyPlus houses will expand very rapidly, posting an average annual growth rate of 32.2 percent in the period from 2016 through 2025. This is thus the fastest-growing technology line in the whole of the lead market for energy efficiency.

Figure 24: Individual technology lines' share of the global market volume in the market segment for energy-efficient appliances in 2016 (in percent)



Source: Roland Berger (2017)

Figure 25: Individual technology lines' share of the global market volume in the market segment for energy-efficient buildings in 2016 (in percent)

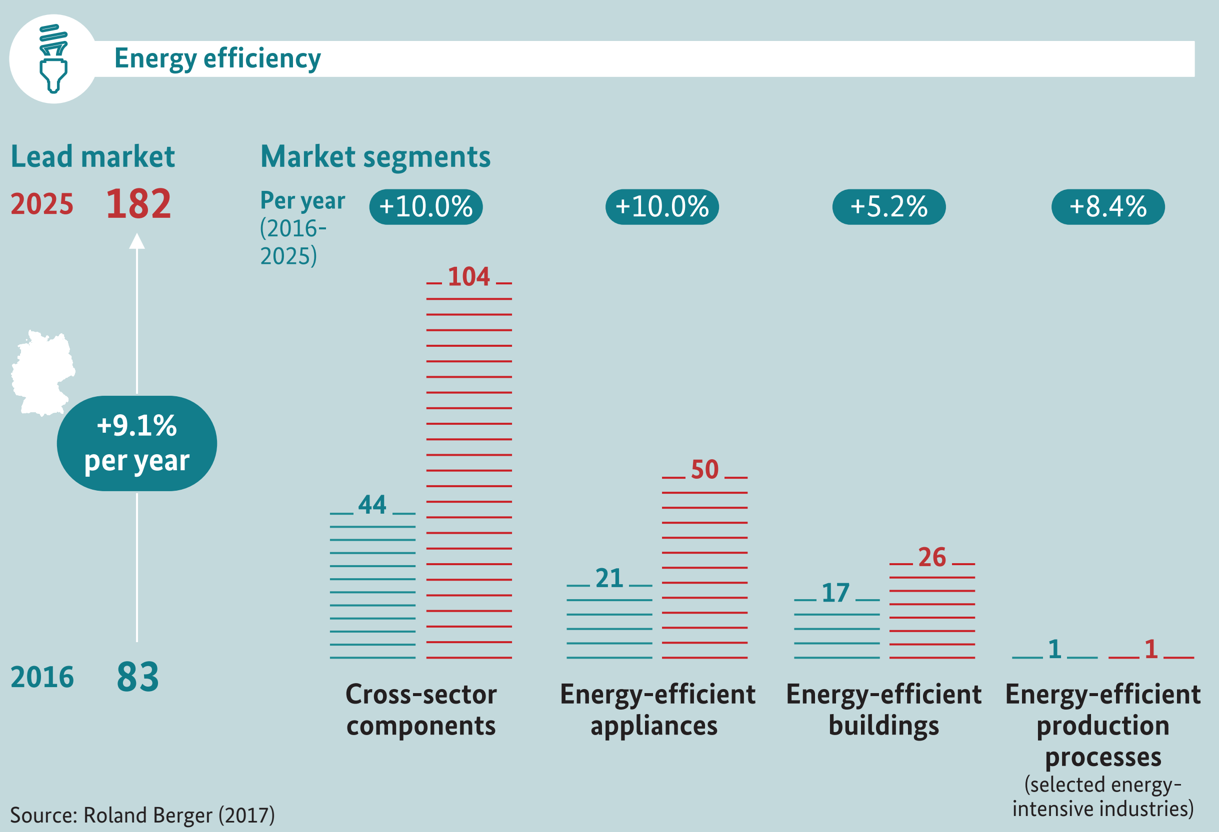


Source: Roland Berger (2017)

Germany: The lead market for energy efficiency

In Germany, the lead market for energy efficiency had a volume of 83 billion technology in 2016. Besides ramping up the generation of power from renewable sources, improving energy efficiency is one of the key ways to reduce greenhouse gas emissions in the energy sector. it follows that energy efficiency is central to the energy sector's transition toward sustainability; and its growing importance is reflected in the development of this lead market in Germany. Average annual growth of 9.1 percent will increase its market volume from 83 billion technology in 2016 to 182 billion technology in 2025 (see Figure 26). As in the international market, cross-sector components account for the largest share of this lead market's volume, although this market segment is developing faster in Germany than on a global scale. Between 2016 and 2025, cross-sector components will grow at an average annual rate of 10 percent in Germany, against 5.7 percent worldwide. The faster pace of growth in the German market segment is attributable in particular to the relatively heavy weighting of industrial value added in this country, as well as to the regulatory frameworks that exist at the national and EU levels. The improvement of energy efficiency is anchored in German and EU energy policy. At manufacturing companies across a broad spread of industries, demand for energy-efficient products, processes and services will increase in the years ahead.

Figure 26: Development of the lead market for energy efficiency in Germany, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

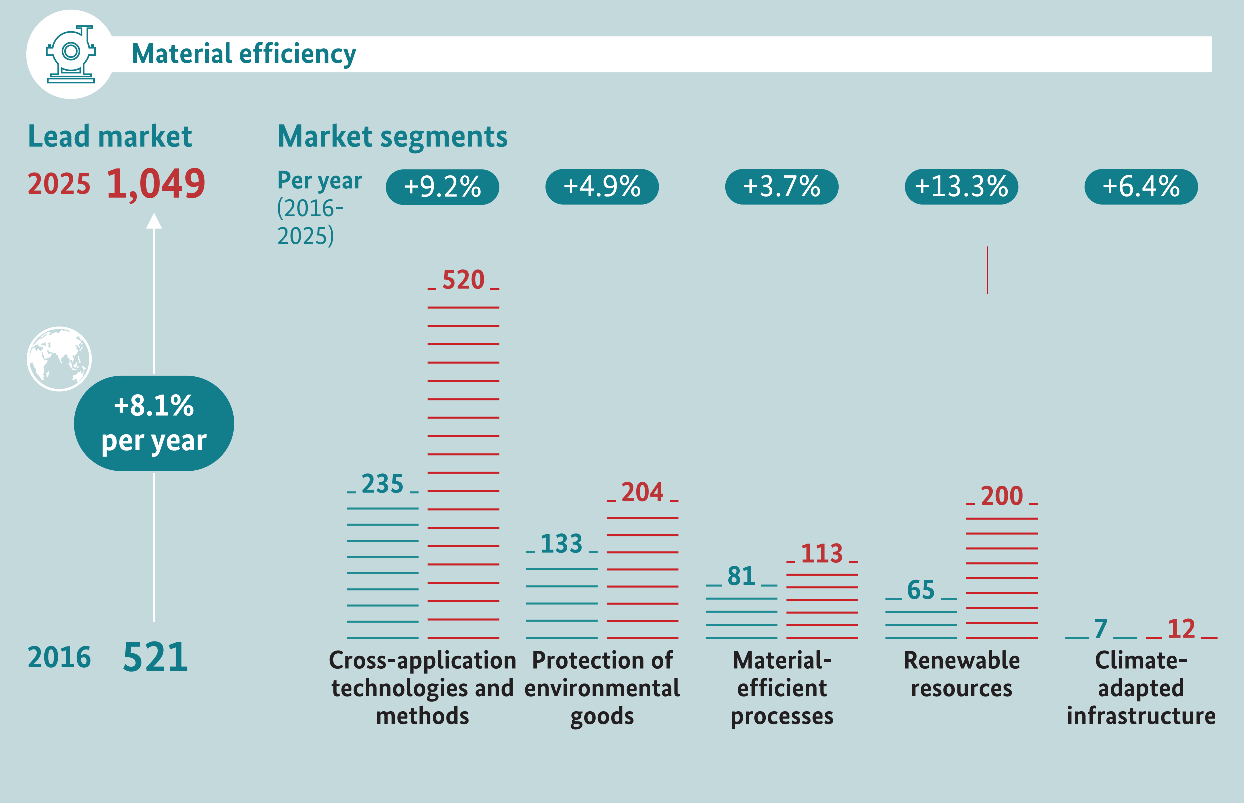
Material efficiency

According to a baseline report by the World Resources Forum,[30] worldwide consumption of raw materials stands at 85 billion tonnes per annum. If nothing is done to curb consumption, the use of natural resources will double by 2050. By contrast, the more efficient use of resources could cut consumption by 28 percent in the same period.[31] If this optimistic scenario, outlined by the World Resources Forum, is to become reality, extensive measures must be taken to improve material efficiency. The products, processes and services in the lead market of the same name play a significant part in achieving this aim.

In 2016, the lead market for material efficiency had a global market volume of 521 billion euros. Average annual growth of 8.1 percent will swell this figure to 1,049 billion euros by 2025 (see Figure 27). This expansion will be driven primarily by the market segments cross-application technologies and renewable resources, which are growing faster than the lead market as a whole.

The market segment for cross-application technologies and methods – abbreviated here to "cross-application technologies" for the sake of convenience – comprises technologies that are not restricted to any particular industries, but are of relevance to applications in a wide range of sectors. Information and communication technologies are classic examples of cross-application technologies that are vitally important to every branch of industry today. Biotechnology, nanotechnology and organic electronics are other good examples. These three lines are seen as key technologies for the ongoing development of material-efficient products and processes – hence the significance attached to them in this analysis of the market segment for cross-application technologies. A global market volume of 235 billion euros – 45 percent of the total global market volume for

Figure 27: Development of the global lead market for material efficiency by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

30 The World Resources Forum is an international panel of scientists operating under the aegis of the United Nations Environment Programme. It applies itself to the sustainable use of resources and produces reports and recommendations on this subject.

31 See Bundesministerium für Wirtschaft und Energie (2017d).

material efficiency – made this the biggest segment of the lead market in 2016. Growing at an average annual rate of 9.2 percent, it will further increase its weighting within the lead market for material efficiency by 2025. In 2025, the global market for cross-application technologies will have a projected volume of 520 billion euros. Nanotechnology had a global market volume of 142.7 billion euros in 2016 and was the largest technology line – both within the market segment for cross-application technologies and within the whole of this lead market. Nanotechnology will retain this leading position in 2025.

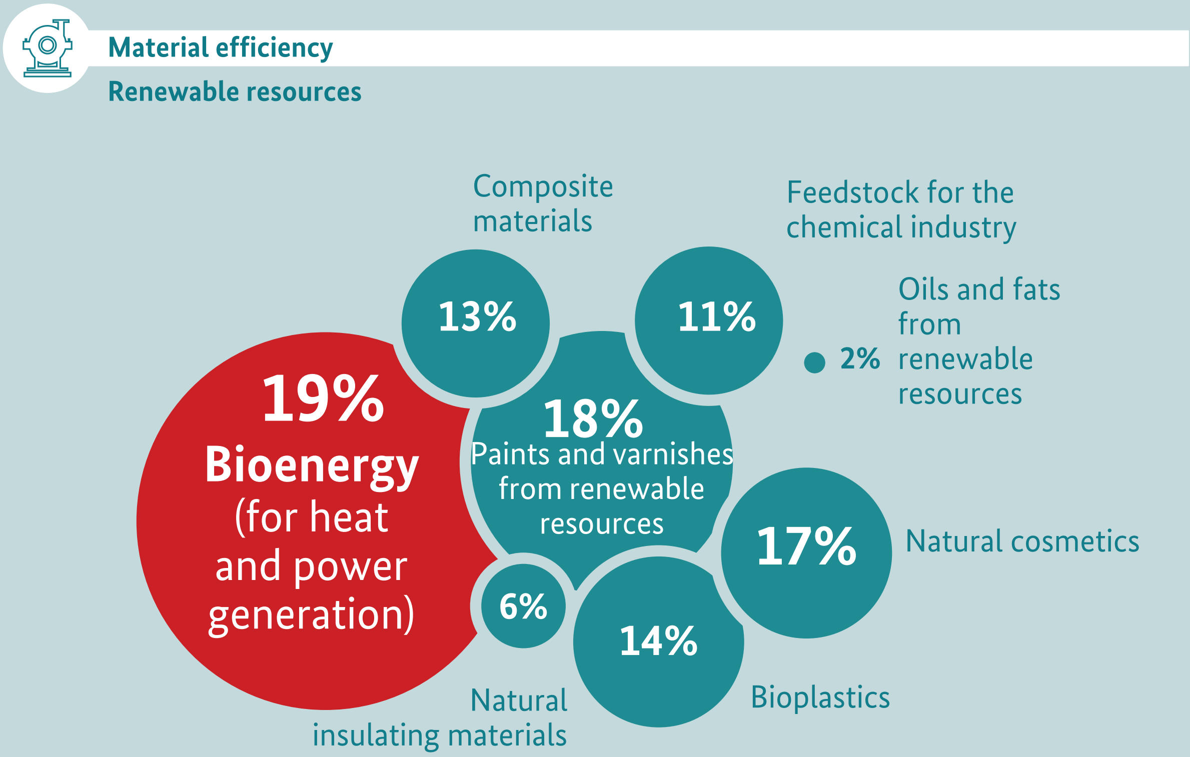
Organic electronics boasts the fastest rate of growth in the market segment for cross-application technologies. This technology line will expand at an average annual rate of 16.8 percent between 2016 and 2025, driven above all by the greater use of organic electronics in photovoltaics, lighting and displays. A global market volume of 71 billion euros is forecast for this technology line in 2025.

In the market segment for renewable resources,[32] a volume of 12.1 billion euros gave the technology line bioenergy (for heat and power generation) a 19 percent share of the global market (see Figure 28). This technology line covers the sale of biomaterials such as pellets, biochar and biogas that are used to generate power and heat. The bioenergy technology line is projected to grow at an average annual rate of 16.7 percent from 2016 through 2025, resulting in a global volume of 48.6 billion euros in 2025. Demand is likewise increasing for paints and varnishes made from renewable resources, many of which are mixed with conventional paints. This trend is reflected in average annual growth of 7.5 percent, which will cause the global market volume for this technology line to nearly double from 11.6 billion euros in 2016 to 22.3 billion euros in 2025.

The composite materials technology line currently has a 13 percent share of the global market volume for material efficiency. Combining natural fibers with plastics creates composite materials (such as wood-plastic composites) that not only reduce the consumption of finite resources, but also often possess superior qualities to conventional fiber composites, including lighter weights and greater stability. Bioplastics accounted for a 14 percent share of the global volume in the market segment for renewable resources in 2016, and this technology line is set to gain considerably in importance in the years to come. In the period to 2025, we expect to see average annual growth of 18 percent – driven by the scaled-up mass production of bio-based plastics.
In terms of global volume, natural cosmetics – worth 11 billion euros – represent a sizeable share (17 percent) of the market segment for renewable resources. Growing consumer demand for consumer products with natural ingredients will continue to buoy this expansion, with average annual growth of 15.1 percent. In 2025, the global market for natural cosmetics will be worth 39 billion euros. The growing importance consumers attach to transparency about ingredients is mirrored in this development.

32 When evaluating the use of renewable resources, it is essential to consider the environmental impact across the entire production and supply chain. For example, if rainforests are cut down or monocultures that are detrimental to biodiversity are established in order to grow energy or industrial crops, the advantages with respect to resource efficiency are greatly reduced or even eliminated.

Figure 28: Individual technology lines' share of the global market volume in the renewable resources market segment in 2016 (in percent)



Source: Roland Berger (2017)

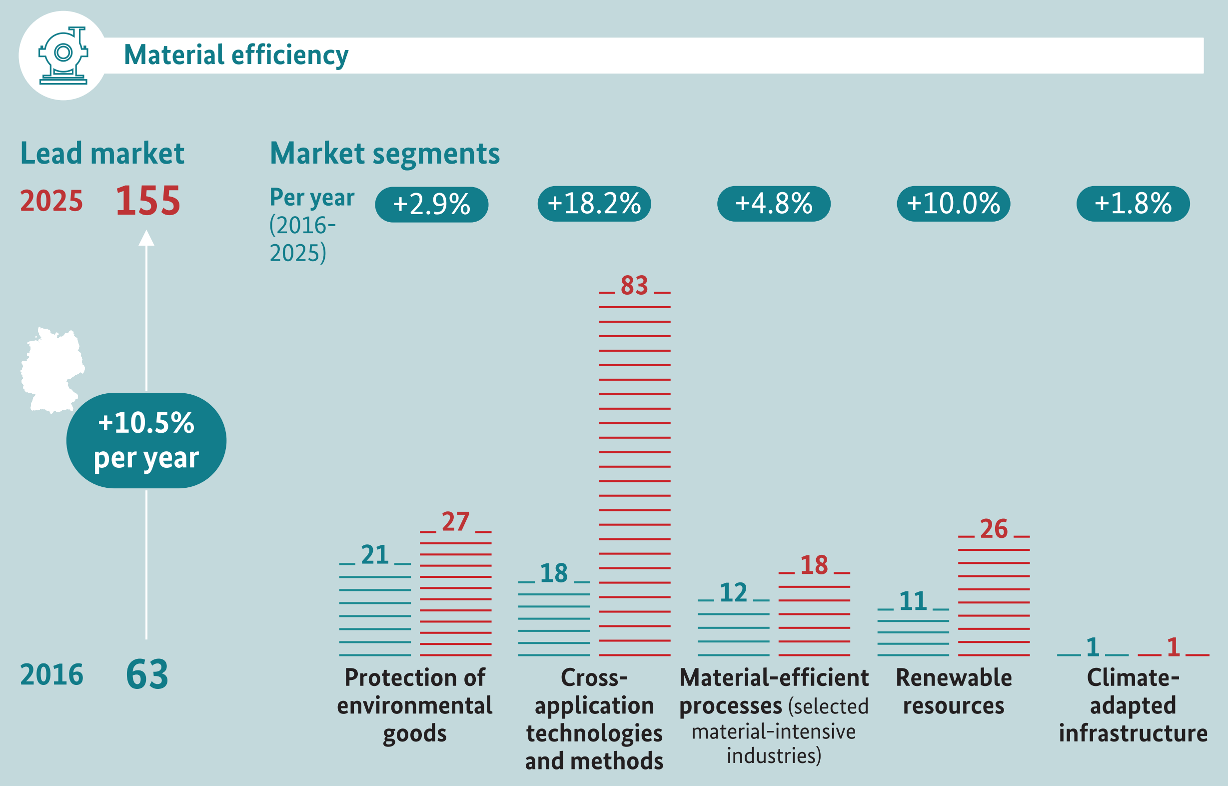
The protection of environmental goods is another segment of the lead market for material efficiency: A close correlation exists between spiraling demand for resources, the increasing extraction of natural resources and the resultant damage and risks to our ecosystems. In 2016, a global market volume of 82.8 billion euros made groundwater protection and water conservation by far the largest technology line in this market segment. In the same year, the technology line nature and landscape conservation had a global market volume of 29.2 billion euros. Emerging nations in particular are now engaging in preventive investment to guard against natural disasters. More money is also being channeled into nature and landscape conservation. Against this backdrop, the latter technology line will realize average annual growth of 11.6 percent between 2016 and 2025, putting its global market volume at 78.4 billion euros in 2025.

The market segment for climate-adapted infrastructure currently has a relatively modest volume of just 6.8 billion euros. Within this segment, flood protection was the largest technology line in 2016, with a global market volume of 5.8 billion euros that will increase to nearly 9 billion euros by 2025. This forecast is based on ramped-up flood protection measures in Europe and in Southeast Asia, Pakistan and India – especially because the danger of disastrous flooding is growing as a consequence of climate change. As extreme weather events become more frequent in many regions, the technology lines storm protection and heat and fire protection will also gain ground in the years ahead.

Germany: The lead market for material efficiency

In Germany, the lead market for material efficiency was worth 63 billion euros in 2016. Growing importance is being attached to improvements in material efficiency, and the key instrument deployed for this purpose is the German government's resource efficiency program. Further expansion is therefore to be expected in this lead market. Average annual growth of 10.5 percent is projected for Germany in the period from 2016 through 2025, leading to a market volume of 155 billion euros in 2025. Cross-application technologies and methods will be the mainstay of this growth, with annual growth rates of 18.2 percent predicted in Germany through 2025. To put that in perspective: The anticipated global growth rate is only 9.2 percent. The divergence can be put down to [Germany's] diverse array of research projects and numerous spin-offs from scientific institutions. In the years to come, these highly innovative enterprises will increasingly bring the fruits of their development work to bear on high-tech products made in Germany. In particular, the market for nanotechnology is experiencing vigorous growth in coatings and equipment to process nanoparticles. By no means least, this development is being supported by programs and initiatives such as the nanotechnology action plan "Nano in Germany", launched in 2015.

Figure 29: Development of the lead market for material efficiency in Germany, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

Urban mining

"Germany has few raw materials." Though often aired in the context of resource efficiency, it is worth taking a closer look at this claim, because Germany is actually richly endowed – at least in terms of secondary raw materials. Vast reserves of resources in the form of anthropogenic material deposits lie hidden in buildings, infrastructure and consumer durables. Unearthing this buried treasure helps conserve natural resources, and one way to do so is to pursue urban mining. Germany's Federal Environment Agency defines this practice as "the integrated management of anthropogenic material deposits with the aim of recovering secondary raw materials from durable goods and deposits".[33] Literal interpretations of the concept of "urban mining" can be misleading: The practice is not confined only to urban deposits of resources, but embraces everything from electrical equipment and cars to infrastructures, buildings and whatever ends up in landfills.

There are many reasons to tap anthropogenic deposits, one of them being the sizeable proportion of reusable materials they contain: Components and machinery, for example, contain lots of metals in pure or highly alloyed form, whereas the same resources occur only in lower concentrations in natural ore deposits: The gold content in an average mobile phone equates to the yield from 16 kilograms of gold ore.

One major challenge in urban mining is that it sometimes takes decades before the material cycles for buildings, infrastructure and consumer durables can be closed. Such lengthy timespans make it difficult to identify what materials are available and determine their composition. That is why urban mining strategies look beyond traditional waste management concepts in the way they analyze material cycles. Urban mining takes a full-lifecycle view of durable goods: Even while they are still in use, it keeps a clear focus on materials to ensure that future resource flows can be forecast and optimized reuse trajectories mapped out at an early stage. There are still gaps in our knowledge of the composition of Germany's anthropogenic material deposits. To plug these gaps, the Federal Environment Agency has launched a project entitled "Mapping the anthropogenic material deposits in Germany".[34]

The Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS also concerns itself with this topic.[35] One area of research for IWKS' scientists is the extraction of reusable resources from material systems such as metallurgical slag and the recovery of metals from mineral and organic sludge. Another issue is the recovery of secondary raw materials from landfills.[36]

33 See Umweltbundesamt (2016b).
34 See Umweltbundesamt (2015a).
35 See Fraunhofer-Projektgruppe für Wertstoffkreisläufe und Ressourcenstrategie IWKS (2017).
36 This niche aspect of urban mining is also referred to as landfill mining.

Carbon capture and utilization: CO_2 as a raw material

Carbon capture and utilization (CCU) is helping us to see CO_2 in a new light. Bedeviled as a "climate killer", carbon dioxide also has the potential to become a source of raw materials. The abbreviation CCU stands for technologies and processes "that use carbon dioxide directly or, after chemical transformation, as a carbon compound in materials and energy sources".[37] The verbal noun "utilization" clearly sets CCU apart from carbon capture and storage (CCS) technology: CCS permanently sequesters CO_2 underground to keep it from escaping into the atmosphere. In contrast, CCU seeks to use CO_2 emissions as an alternative source of carbon. In keeping with the idea of the circular economy, this approach enables industrial CO_2 cycles to be closed.

The CO_2 for CCU technologies can be recovered primarily from emissions generated by industrial and power plants, where it is filtered from flue gas. Given the relatively high costs and slack demand, however, the relevant processes are not yet firmly established. Nor have reservations about risks to the environment – during the transportation of CO_2, for example –yet been fully resolved.

The atmosphere itself could also be a potential source of CO_2. Chemical/technical processes could filter existing CO_2 emissions out of the air (by means of direct air capture), although this approach is not yet ready for commercial use.

Once captured, CO_2 can be put to a variety of uses. Physical utilization exploits CO_2 in a solid or liquid state – in dry ice, fire extinguishers and drinks, for example. After chemical transformation, it can serve as a raw material to produce carbon compounds with high-grade energy properties (material recovery). These properties are needed above all in pharmaceutical products, solvents and fertilizers. Liquid fuels and synthetic gases can also be produced with CO_2 and used to store energy. As things stand, however, these energy recovery processes are only deployed in demo installations.

A recent study investigated what CCU technologies might contribute to climate and innovation policy.[38] It found that CCU harbors significant potential to mitigate climate change, mainly through gains in energy efficiency and by substituting fossil resources. The study nevertheless concludes that it will be decades before carbon capture and utilization can be deployed on a broad front.

37 See Institute for Advanced Sustainability Studies (IASS) (2014).
38 See Piria, Raffaele/Naims, Henriette/Lorente Lafuente, Ana Maria (2016).

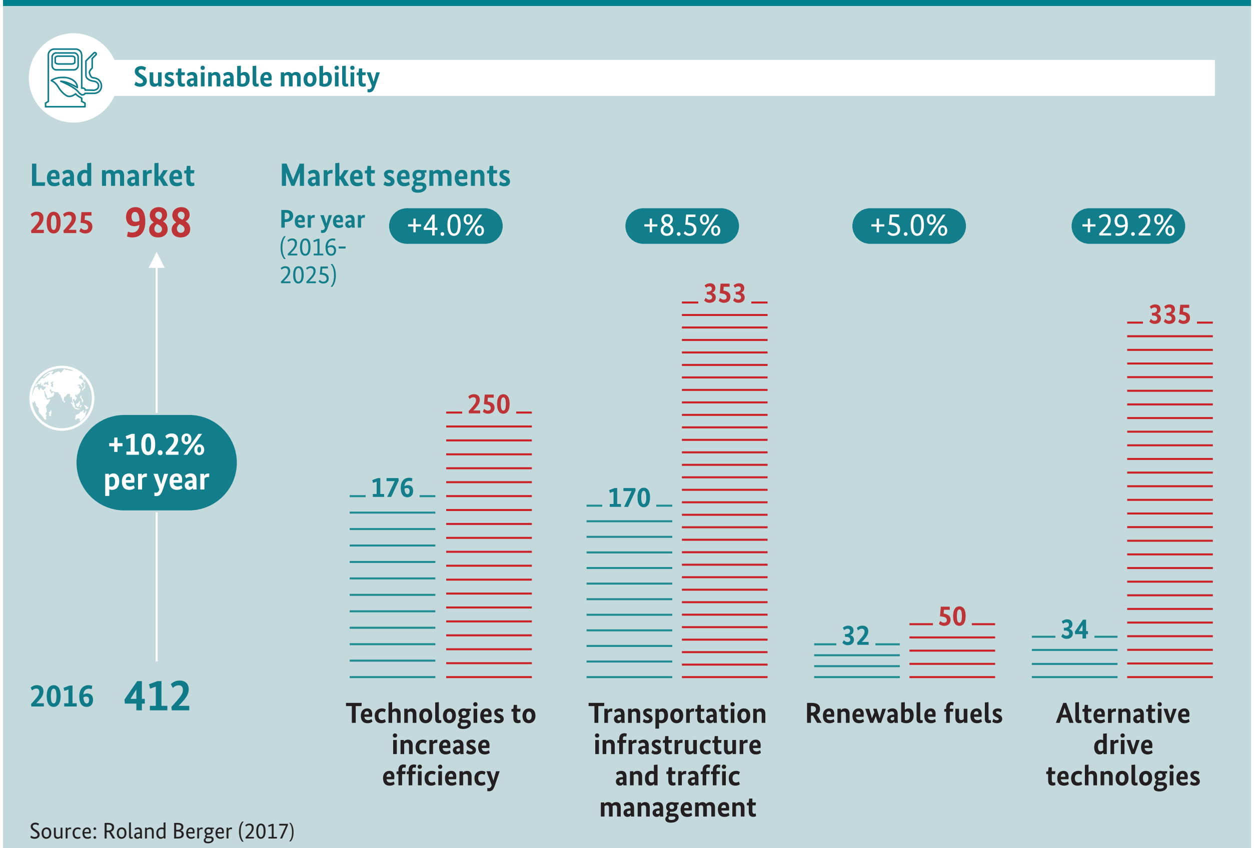
Sustainable mobility

The transport sector is responsible for 24 percent of the world's greenhouse gas emissions.[39] The conclusion is obvious: Global climate policy targets can be met only if we succeed in reducing mobility-related CO_2 emissions. Closer inspection of the transport sector identifies motorized road traffic – cars, trucks, buses and motorcycles – as the predominant source of CO_2 emissions. 75 percent of all the greenhouse gases emitted by the transport sector are churned out on our roads,[40] which is why climate-friendly technologies for use in cars and trucks are of special importance to efforts to mitigate climate change.

It is true that, on average, cars and trucks in Germany produce fewer greenhouse gas emissions and air pollutants than in the past. Since 1995, per-kilometer CO_2 emissions have decreased on average by 13 percent for cars and 31 percent for trucks. The downside is that more vehicles in general – and more trucks in particular – are now out and about than two decades ago. As a result, greenhouse gas emissions from road freight transportation are actually 16 percent higher than in 1995. This growing traffic volume is a key reason why the transport sector has so far contributed less than other sectors to the realization of Germany's climate policy target: to reduce greenhouse gases by 40 percent relative to 1990 levels by 2020. By 2014, the transport sector had managed to reduce its CO_2 emissions by a mere 2.6 percent against the base year 1990. Overall, CO_2 emissions are down by 27.7 percent in the same period.[41] Mobility must therefore experience a sustainable transformation if greenhouse gases and other harmful impacts on the environment are to be reduced in the transport sector.

Globally, sustainable mobility is the fastest-growing lead market in the green tech industry. Between 2016 and 2025, it will expand at an average annual rate of 10.2 percent. The global market volume of 412 billion euros recorded in 2016 will thus climb to 988 billion euros in 2025 (see Figure 30).

Figure 30: Volume development in the global lead market for sustainable mobility by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

39 See International Energy Agency (2016c), page 97.
40 See BDL – Bundesverband der Deutschen Luftverkehrswirtschaft (2017), page 6.
41 See Umweltbundesamt (2017d).

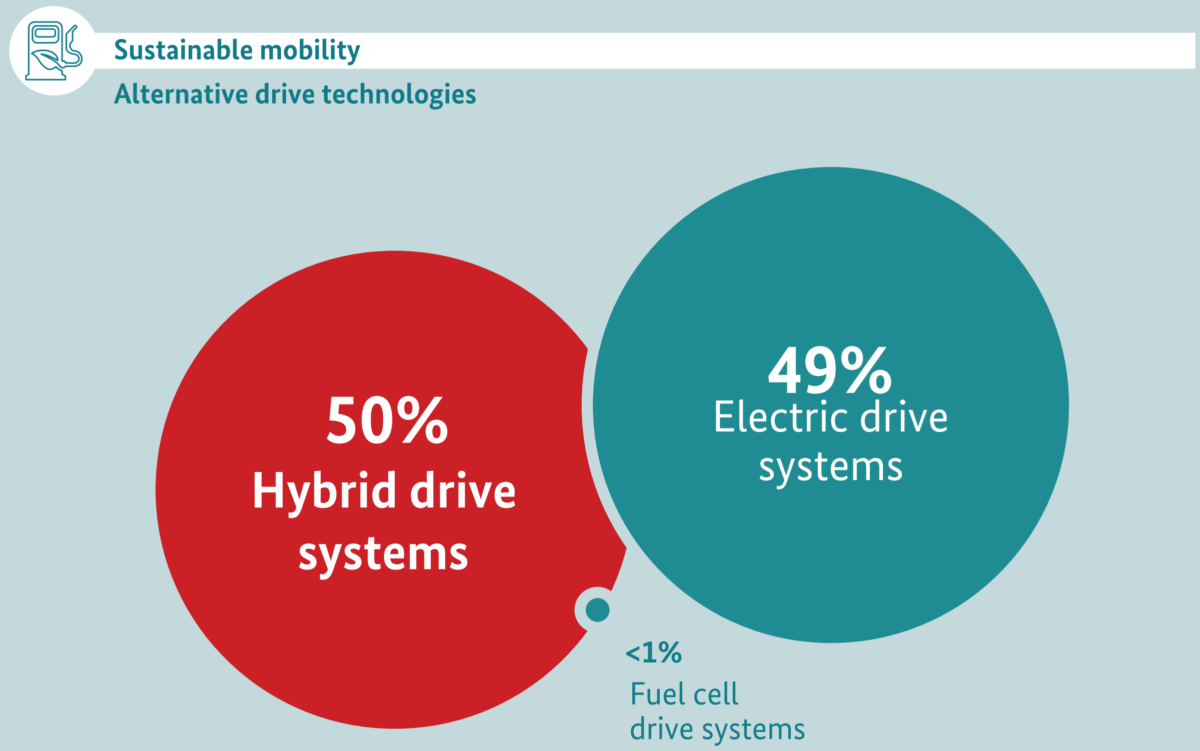
By far the strongest growth will be in alternative drive technologies not only for cars, but also for other modes of transportation such as e-buses, e-bikes and e-scooters. In the period from 2016 through 2025, the market segment for alternative drive technologies will record average annual growth of 29.2 percent. It will thus reach a projected global market volume of 335 billion euros by 2025 – up from 34 billion euros in 2016. The impetus for this rapid growth will come primarily from the technology line electric drive systems, which will reach the mass production phase. An average annual growth rate of 35.6 percent will boost this technology line's share of the total volume for this market segment from 49 percent in 2016 to 76 percent in 2025.

This development represents a shift in the relative weightings of the technology lines within the market segment. In 2016, hybrid drive systems, which have already reached maturity, accounted for a 50 percent share of the global volume in this market segment (see Figure 31). By 2025, that share will have shrunk to 21 percent. Fuel cells will post forceful average annual growth, albeit starting from a very low level.

The worldwide market volume for this technology line was 77 million euros in 2016. Fuel cell drive systems currently only exist in pre-series versions, and the cost of this technology is still relatively high. As with the charging infrastructure for battery-electric vehicles, the hydrogen refueling infrastructure needed to get the market for fuel cell vehicles up and running is still lacking.

In the market segment for efficiency gains, lightweight engineering technologies are a definite growth trend. These technologies reduce vehicle weights and hence fuel consumption. In combination with improved aerodynamics, rigorous lightweight engineering can significantly increase energy efficiency in cars. This makes the discipline an important area for achieving fuel savings in automotive engineering and the aviation industry. Lightweight engineering technologies also help cut costs, for example by reducing demand for materials or by substituting cheaper materials (such as plastic springs) for more expensive ones (steel springs). The global market volume for this technology line was 76.2 billion euros in 2016 and will double to

Figure 31: Individual technology lines' share of the global market volume in the alternative drive technologies market segment in 2016 (in percent)



Source: Roland Berger (2017)

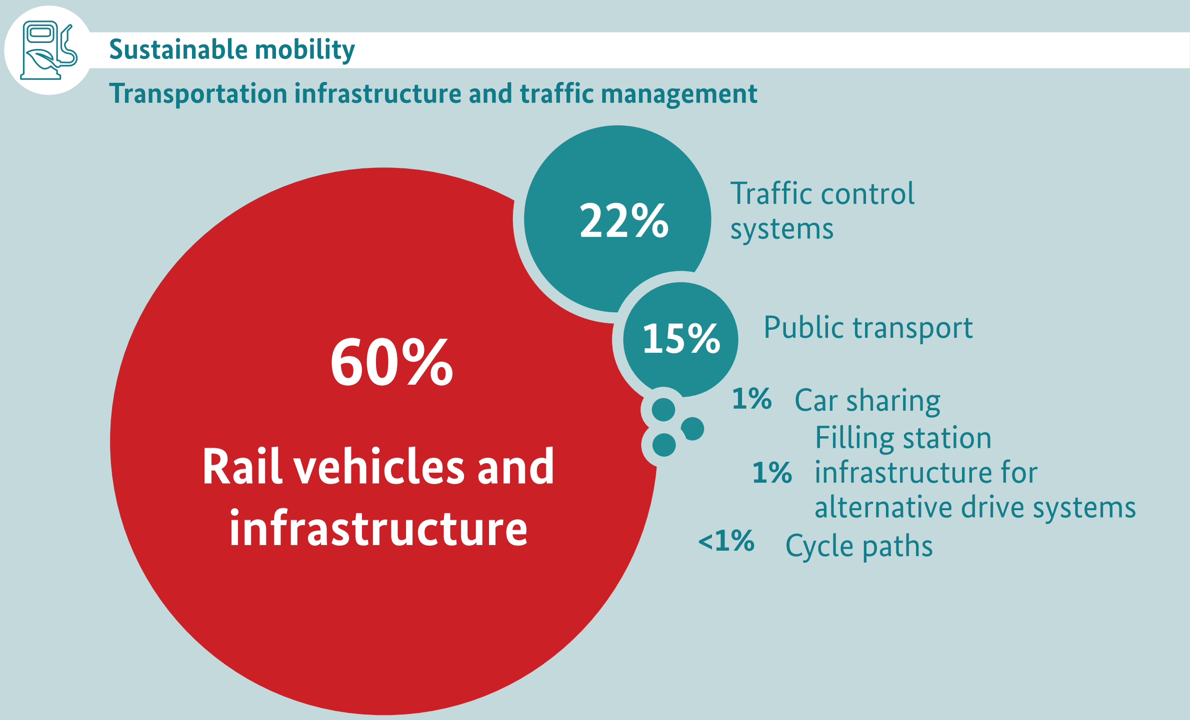
153.1 billion euros by 2025, reflecting average annual growth of 8.1 percent. Efficiency gains in combustion engines remain an important aspect of the lead market for sustainable mobility. This technology line made up 41 percent of the global market volume in the market segment for efficiency gains in 2016. Despite the increasing pene-tration of alternative drive systems, the majority of cars worldwide will continue to feature combustion engines in the coming years. These engines are also needed in combination with electric drive systems, for example in hybrid vehicles and as range extenders in electric cars.

The market segment for traffic management and transportation infrastructure had a global market volume of 169.9 billion euros in 2016. By far the largest share of this segment (62 percent) was accounted for by the technology line rail vehicles and rail infrastructure (see Figure 32). The dominant position of this technology line will not change in the years ahead, and its global market volume will be close to 149 billion euros in 2025. Although many cities are straining at the limits of their capacity to absorb individual motorized transportation, more and more people will live in urban spaces in the future. At the same time, there is a growing awareness of how vehicular traffic pollutes the environment. All these trends are causing public transport to gain in importance – a development reflected in average annual growth of 5.4 percent in the latter technology line between 2016 and 2025. The global market volume for the public transport technology line will increase from 25.2 billion euros in 2016 to 40.6 billion euros in 2025. Also on the up are investments in cycle paths, with cycling attracting new adherents in more and more countries as an alternative to using the car for short urban journeys. The global market volume for car sharing currently remains low at 1.8 billion euros. However, this technology line will grow impressively at an average annual rate of 30 percent, reaching a projected global market volume of 19 billion euros in 2025.

The public charging and refueling infrastructure (for hydrogen) must be expanded if vehicles with alternative drive systems are to realize greater market penetration.[42] In 2016, the global market volume for filling station infrastructure for alternative drive systems was 1.8 billion euros. Backed by growing demand for vehicles with alternative drive systems, this technology line will develop extremely rapidly in the period from 2016 through 2025, with average annual growth of 55.6 percent. In 2025, the global market volume will tip 98 billion euros.

42 We include hybrid, electric and fuel cell drive systems in this category.

Figure 32: Individual technology lines' share of the global market volume in the transportation infrastructure and traffic management market segment in 2016 (in percent)



Source: Roland Berger (2017)

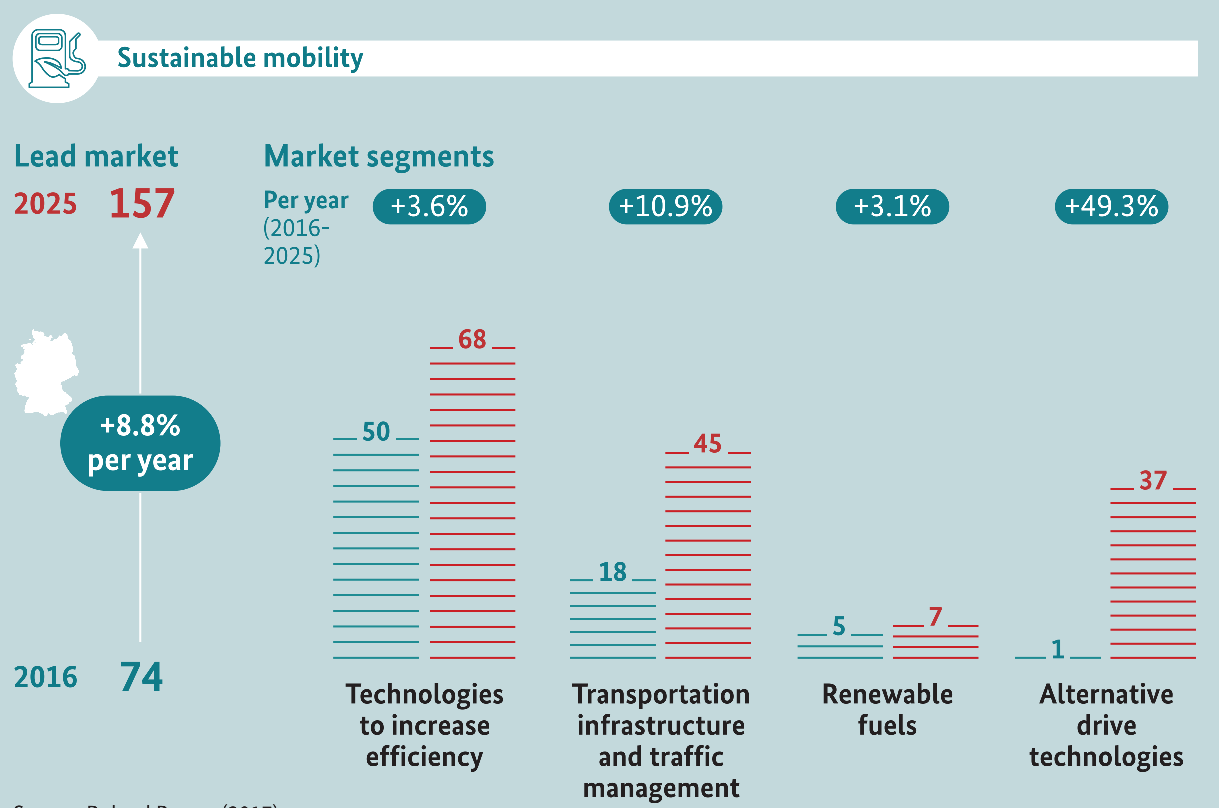
Germany: The lead market for sustainable mobility

The lead market for sustainable mobility had a volume of 74 billion euros in Germany in 2016. Thanks to an average annual growth rate of 8.8 percent, it is projected to reach a volume of 157 billion euros in 2025 (see Figure 33).

Alternative drive technologies are expanding at an exceptionally fast pace. Between 2016 and 2025, this market segment will see its German volume surge from 1 billion euros to 37 billion euros. That equates to average annual growth of 49.3 percent. The market penetration of e-mobility is the main factor behind this frantic development. On a global level, growth in this market segment is lower (29.2 percent). The discrepancy suggests that e-mobility is set to gain ever greater significance in Germany in the years ahead. In the wake of the diesel scandal that received wide media coverage in summer 2017, it is likely that the "mobility transition" will gain considerable traction in Germany.

More and more countries have declared the combustion engine to be obsolete. The UK and France are targeting a ban on combustion engines in newly registered vehicles as of 2040. India plans to do the same from 2030 and Norway from 2025. Germany's heavily export-oriented car markets cannot escape the pressure that is building on international markets. It is therefore reasonable to assume that more and more e-models with appealing technology and attractive prices will come onto the market in the future. That in turn should fuel greater interest and acceptance on the demand side.

Figure 33: Volume development in the global lead market for waste management and recycling by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

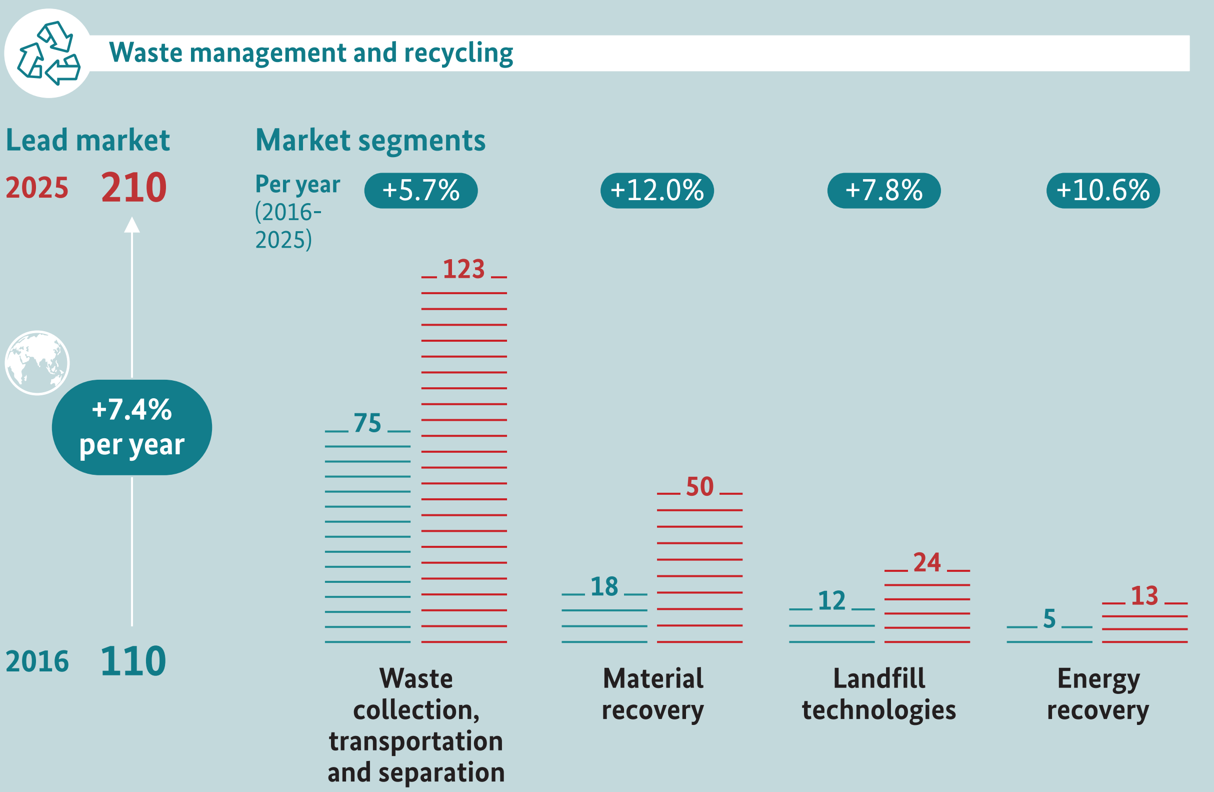
Waste management and recycling

Greater importance than in the past is now being attached to the waste management industry all around the world – not least because its relevance to environmental protection, the mitigation of climate change and the sustainable use of resources is becoming ever more apparent. Starting from a global market volume of 110 billion euros in 2016, this lead market will swell to 210 billion euros by 2025 at an average annual growth rate of 7.4 percent (see Figure 34).

Waste collection, transportation and separation remains the dominant segment of the lead market for waste management and recycling. The global volume for this market segment was 75 billion euros in 2016, giving it a 75 percent share of the whole waste management and recycling industry. In the period from 2016 through 2025, the market segment for waste collection, transportation and separation will grow at an average annual rate of 5.7 percent, bringing the global market volume to 210 billion euros in 2025. With a global market volume of 65 billion euros in 2016, waste collection and transportation was easily the largest technology line in the lead market for waste management and recycling. Its share of the entire industry's global market volume was 59 percent in the same year. The waste separation technology line will expand at an average annual rate of 13.8 percent between 2016 and 2025. This trend testifies to some emerging nations' growing willingness to invest. China, where automated waste separation and recycling plants are increasingly taking over from manual waste separation, is a case in point.

The global market segment for material recovery spans the technology lines mechanical recycling and feedstock recycling and was worth 18 billion euros in 2016. Of the two lines, feedstock recycling predominates. Its global market volume totaled 13.6 billion euros in 2016, accounting for a 76 percent share of the global volume in the material recovery segment. Feedstock recycling's global volume should be 33 billion euros in 2025 – two thirds of the global volume for the entire material recovery segment. Nevertheless, mechanical recycling too will gain in importance in this market segment. Between 2016 and 2025, it will realize average annual growth of 16.5 percent, while feedstock recycling will expand at the slightly slower rate of 10.3 percent. From the point of view of environmental policy, this trend is heading in the right direction, as mechanical recycling generally has a smaller ecological footprint.

Figure 34: Volume development in the global lead market for waste management and recycling by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

The lead market for waste management and recycling

Germany's waste management and recycling industry was worth 20 billion euros in 2016. Average annual growth of 5.7 percent is predicted through 2025, which should raise the market volume to 32 billion euros (see Figure 35). As in the international lead market, the waste management and recycling industry in Germany is likewise dominated by the market segment for waste collection, transportation and separation.

Figure 35: Volume development in the lead market for waste management and recycling in Germany, 2016 to 2025 (billion euros, average annual change in percent)

Source: Roland Berger (2017)

Obsolescence

One Latin-English dictionary defines the verb "obsolescere" as "to fall into disuse, to be forgotten about". Another possible rendering is "to go out of fashion". Today, the English word "obsolescence" is used to denote the aging of products. It is the subject of heated debate, for two reasons: Some consumers allege that manufacturers deliberately build deficiencies into their devices and equipment to limit their lifecycle a priori. The suspicion is that this "planned obsolescence" takes effect shortly after any relevant warranty and guarantee periods have expired. On the other hand, the shorter lifespan of products in today's "throwaway society" constitutes an ecological problem. The process of manufacturing products places a burden on the environment and the climate. If yesterday's products are replaced more quickly by new purchases, this could negate the positive effects of resource efficiency.

A study by Öko-Institut e.V. (the Institute for Applied Ecology) and the University of Bonn[43] recently investigated the phenomenon of obsolescence. The study focused on 13 groups of electrical and electronic devices. It found that refrigerators, televisions, washing machines, smartphones and notebooks are indeed being used for ever shorter periods. For example, the average service life of large household appliances declined from 14.1 years to 13 years between 2004 and 2012. In the case of notebooks, the period from purchase to replacement purchase – known as the initial use period – shrank from 5.7 years to 5.1 years between 2007 and 2012. More than 40 percent of users in Germany replace their mobile phone after two years.[44]

There are many and varied reasons for obsolescence. Functional obsolescence occurs when the functional and technical demands placed on a product change. It may no longer be possible to use a product because its interfaces are no longer compatible, for instance. The term psychological obsolescence describes the practice of replacing products that still work properly because fashions, consumption patterns or technical trends have changed. Lastly, when it would cost more to repair or service a product than to buy a new one, one speaks of economic obsolescence. The Öko-Institut study clearly showed that, in consumer electronics and information technology, advances in technology and the desire for a better piece of equipment are often the reason for a new purchase. And while no evidence of planned obsolescence was found, the Federal Environment Agency sees a need for action to counteract product lifecycles that are too short. "The service life of many devices is too short," says Maria Krautzberger, president of Germany's central environmental authority. "From an ecological perspective, that is unacceptable. Manufacturing products consumes valuable resources. Pollutants and greenhouse gases burden the environment and the climate. We need to think about minimum requirements in terms of product lifecycle and quality."[45]

43 See Umweltbundesamt (eds.) (2016c).
44 See Öko-Institut e.V. (2016), page 4f.
45 See Umweltbundesamt (2016d).

Plastic waste in the oceans

In February 2017, a Cuvier's beaked whale was stranded off the coast of Norway. When scientists from the University of Bergen dissected the animal, they found 30 plastic bags and large quantities of microplastic in its stomach. The plastic waste had formed a plug, with the result that the whale was severely weakened and emaciated and had had to be put down.[46]

Around 2.7 million tonnes of plastic finds its way into the oceans every year. It takes centuries for plastic to degrade: A robust plastic bottle can survive for 400 years. On average, every square kilometer of the ocean's surface contains 13,000 particles of plastic debris.[47] Gigantic vortexes of trash have formed in some marine areas, the biggest of which is "The Great Pacific Garbage Patch" in the northeastern Pacific, north of Hawaii. This patch covers an area as big as Central Europe.

Plastic waste poses a huge threat to sea creatures and seabirds. At least a million seabirds and 100,000 other marine organisms die as a result every year. They get caught up in or strangled by bits of nets or packaging materials.[48] When the sun, seawater and the ocean swell causes plastic debris to disintegrate, it is swallowed by fish and seabirds. The indigestible material clogs their stomachs and the creatures starve to death.

As plastics decompose, they also release toxic additives and additives with hormonal effects such as softening agents, flame retardants and UV filters. Microorganisms living in the oceans have no way of breaking down these plastics, which are left floating around as microparticles. The proportion of microplastic in the oceans is observably increasing: Scientists from the University of Oldenburg, for example, have found microplastic in all fecal samples gathered from common and gray seals in the mudflats on the shores of Lower Saxony.[49]

Microplastic finds its way into the oceans not only as plastic waste disintegrates, but also in the form of direct aquatic input. Many cosmetics and body care products such as peelings, shower gels and toothpaste contain plastics (including polyethylene). Every time clothes made of fleece and other polyester or polyacrylic fabrics are washed, microplastic particles are flushed out and – since sewage treatment plants are unable to filter out the tiny particles – end up in the sea.

Under the motto "Stop! Micro Waste", Berlin-based Langbrett developed the "GuppyFriend" for which it has filed a patent. Measuring 50 x 60 centimeters and made of industrial fabric, this bag can be filled with dirty linen and placed in the drum of a washing machine. The fibers flushed out of sports, fleece and other plastic textiles get caught in the bag – and go no further.[50]

The pollution of the oceans with microplastic endangers the marine ecosystem. But it can also directly affect humans via the food chain. Particles of microplastic bind persistent toxic pollutants to their surface, which in turn can cause harmful substances to be enriched throughout the food chain.

46 Unattributed (2017b).
47 See Umweltbundesamt (2015b).
48 Ibid.
49 Ibid.
50 See Willenbrock, Harald (2016).

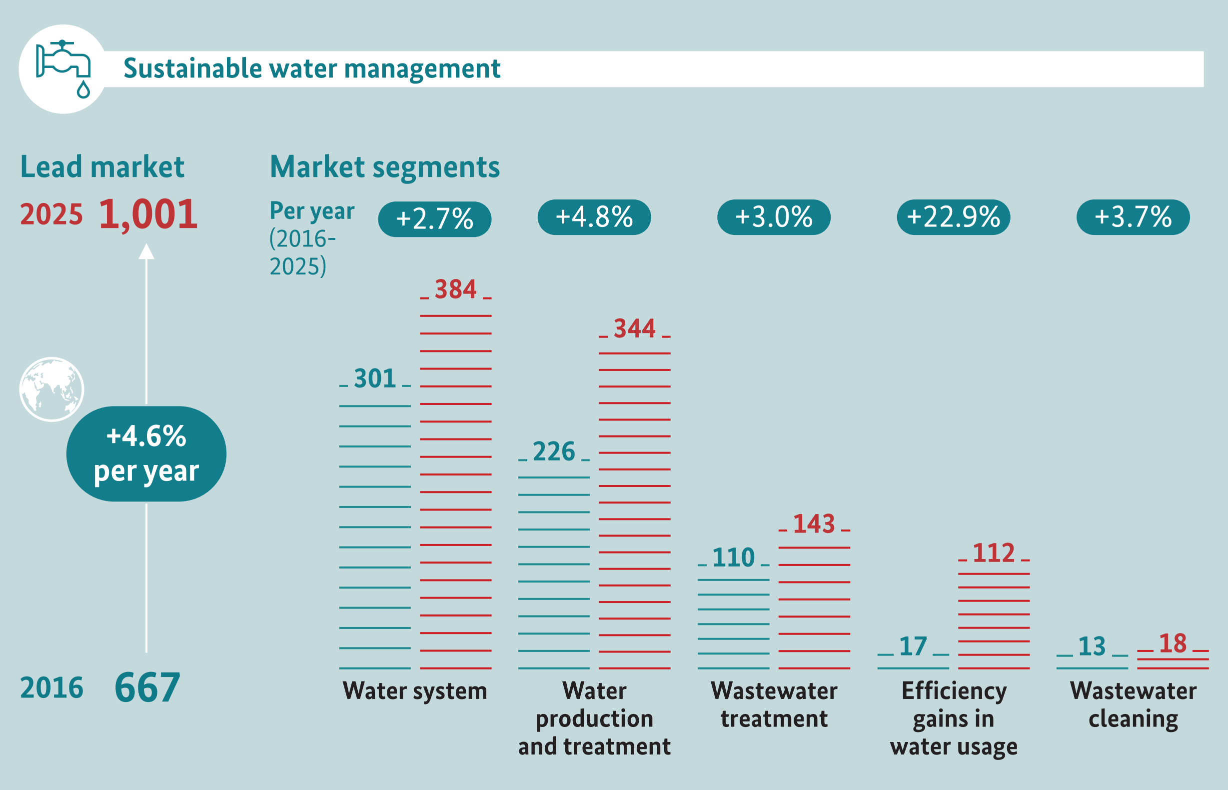
Sustainable water management

Clean water for everyone on the planet is one of the sustainable development goals formulated in the 2030 Agenda. Yet meeting this target remains a serious challenge – especially in the face of a growing global population, increasing water consumption, ever greater pollution of our water and a water crisis exacerbated by climate change in many parts of the world. The lead market for sustainable water management therefore clearly has a pivotal role to play – a fact reflected in the development of the global market volume, which was 667 billion euros in 2016. Given an average annual growth rate of 4.6 percent, the market volume is forecast to top the one billion mark in 2025 (see Figure 36). Globally, the market segment for efficiency gains in water usage harbors the greatest potential going forward.

In the market segment for efficiency gains in water usage, volume is distributed across three technology lines that differ in terms of their areas of application: water efficiency technologies in agriculture, in commercial and industrial areas, and in households (see Figure 37). Due to global population expansion, water efficiency technologies in agriculture are one of the growth drivers in the lead market for sustainable water management. In the period from 2016 through 2025, this technology will grow by an annual average of 20.3 percent, with the global market volume rising from 13 billion euros in 2016 to 68 billion euros in 2025.

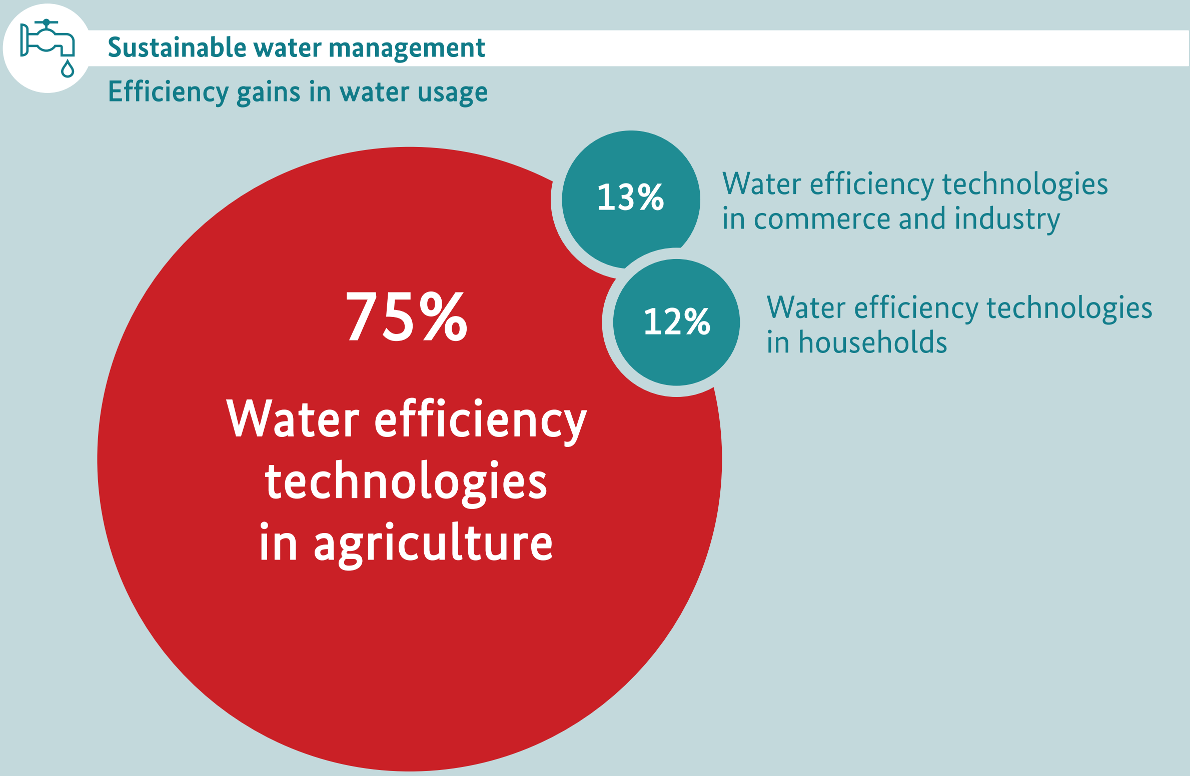
This development means that the market segment for efficiency gains in water usage will increase its share of the total lead market from 2.6 percent in 2016 to 11.2 percent in 2025. The crucial factor behind this forceful growth is increasing demand for artificial irrigation of agricultural land. Agricultural areas with starkly variable climatic conditions and a chronic shortage of water are particularly dependent on the use of irrgation technologies to produce adequate harvests for their growing populations. Even in regions that essentially have a sufficient supply of water, irrigation technologies are increasingly also being used for special crops. Interaction between infrastructure, technology and the practice of irrigation makes a decisive contribution to the optimal use of farmland. Especially in emerging nations, water efficiency technologies play a key role in the transformation to sustainable agriculture.

Figure 36: Volume development in the global lead market for sustainable water management by market segment, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

Figure 37: Individual technology lines' share of the global market volume in the market segment for efficiency gains in water usage in 2016 (in percent)



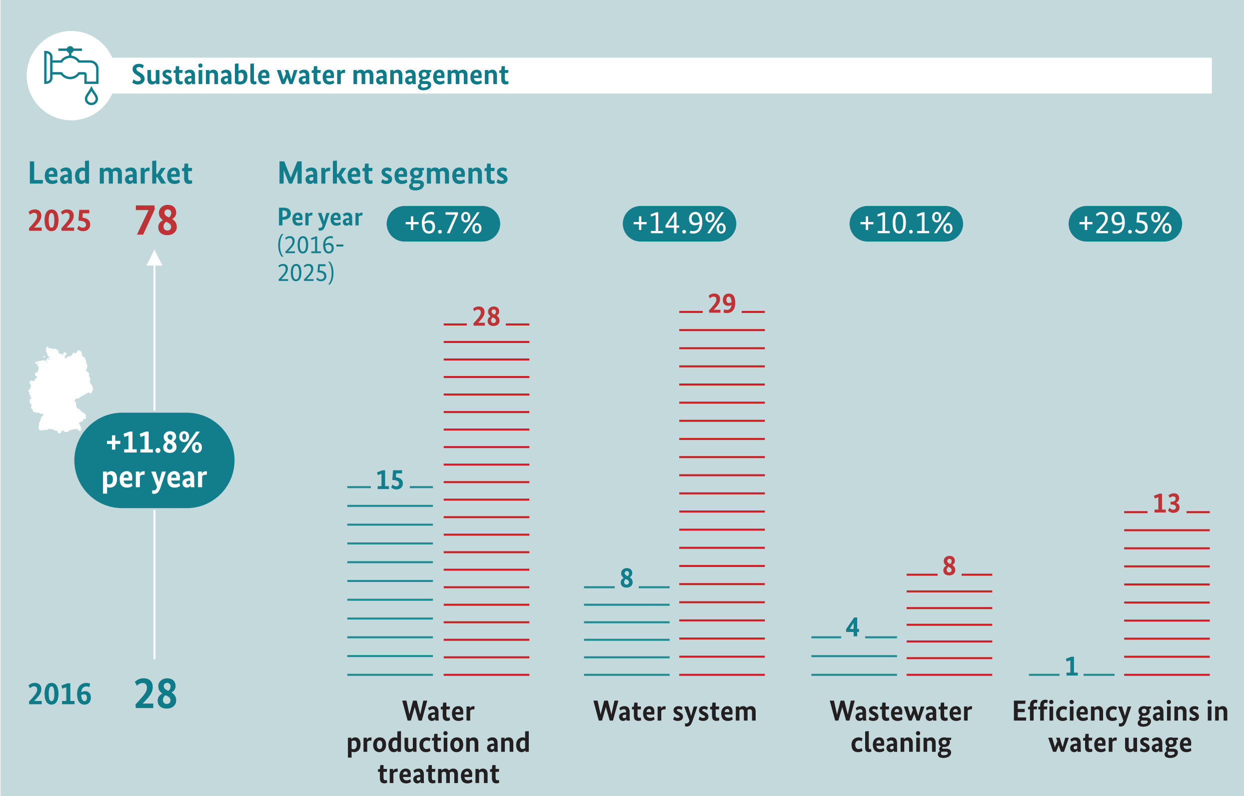
Source: Roland Berger (2017)

The market segment for water production and treatment was worth 225.7 billion euros in 2016, representing a third of the lead market for sustainable water management. Between 2016 and 2025, average annual growth in this market segment will be 4.8 percent. Again, global population growth is a key driver of this expansion. With average annual growth of 6.0 percent, water treatment will slightly outpace the lead market as a whole. The water distribution technology line – part of the water system market segment – had a global market volume of 210.4 billion euros in 2016, thus accounting for a 32 percent of the total lead market for sustainable water management. Water distribution is an investment-intensive technology line whose growth is influenced by regulation in many countries. The global market volume for this technology line is forecast to rise to 266 billion euros by 2025. Wastewater collection and transportation – the second technology line in the water system market segment – is currently still characterized by lower technological standards and is less investment-intensive than water distribution. The global market volume for wastewater collection and transportation is correspondingly smaller, at 90.4 billion euros in 2016, though it will increase to 117.6 billion euros in 2025.

Germany: The lead market for sustainable water management

Sustainable water management is expanding at a faster rate in Germany than internationally. In the period from 2016 through 2025, this lead market will grow here by an annual average of 11.8 percent (see Figure 38), against a global average annual growth rate of 4.6 percent. One reason for this discrepancy is that relatively heavy investment in the German water system is pending in the next few years. First, the investment logjam accumulated in recent years needs to be worked off. At the same time, however, the country's water system must be aligned with changed conditions: Efficiency measures and a dwindling population in some regions mean that the water system now needs less capacity. This market segment was worth 8 billion euros in 2016 and is projected to increase to 29 billion euros in 2025.

Figure 38: Volume development in the lead market for sustainable water management in Germany, 2016 to 2025 (billion euros, average annual change in percent)



Source: Roland Berger (2017)

Anthropogenic micropollutants in the water cycle

Germany's drinking water is of a high quality. Official reports by the Federal Environment Agency and the Federal Ministry for the Environment routinely give top marks to what comes out of the country's taps. To maintain these high standards, the environmental authorities, public health departments and water utilities subject drinking water to meticulous controls. Advances in measuring methods now even allow them to detect what are known as trace elements, the need to deal with which is seen as "one of the predominant topics in water management".[51]

Trace elements are chemical substances that occur in minute concentrations of millionths or even billionths. In this context, chemical substances created by humans are referred to as anthropogenic micropollutants. They include the active ingredients in medicines, scents used in detergents, cleaning agents and cosmetics, softening agents in plastics, plant protection agents, and biocides.[52]

Trace elements enter the water cycle via household sewage, via commercial and industrial wastewater, and via surface run-off, seepage and groundwater run-off from agricultural land. Many trace elements can be degraded at wastewater treatment plants only in part or not at all.[53] As a result, they find their way into waterways and groundwater. Degradation in treatment plants is possible only with the aid of a fourth purification stage that uses either oxidation processes with ozone or adsorption to activated carbon to eliminate trace elements from wastewater.

The concentrations of trace elements or micropollutants found in water are generally believed to be harmless to consumers. Given the current state of scientific knowledge, however, it is not possible to completely rule out negative effects on the environment in the long term.[54] Following the principle that it is better to be safe than sorry, steps are thus being taken to reduce the entry of anthropogenic micropollutants into the water cycle.

Possible toxic impacts on aquatic organisms include stunted growth, restricted reproduction and disruptions during embryonic development, metabolic disorders and behavioral problems. For example, cichlids that were exposed to psychotropic drugs from the benzodiazepine class became reckless and were more frequently caught by predators.[55]

Evidence has been found of ever larger quantities of pharmaceutical residues in water. This problem is likely to get worse as demographic change increases the number of older people in society and the consumption of medication rises accordingly. Antibiotics administered in the context of livestock farming likewise end up in the groundwater. Given the danger that multiresistant germs may form, experts see this development as risky and are calling for thresholds to limit the level of human and veterinary drugs in groundwater.[56]

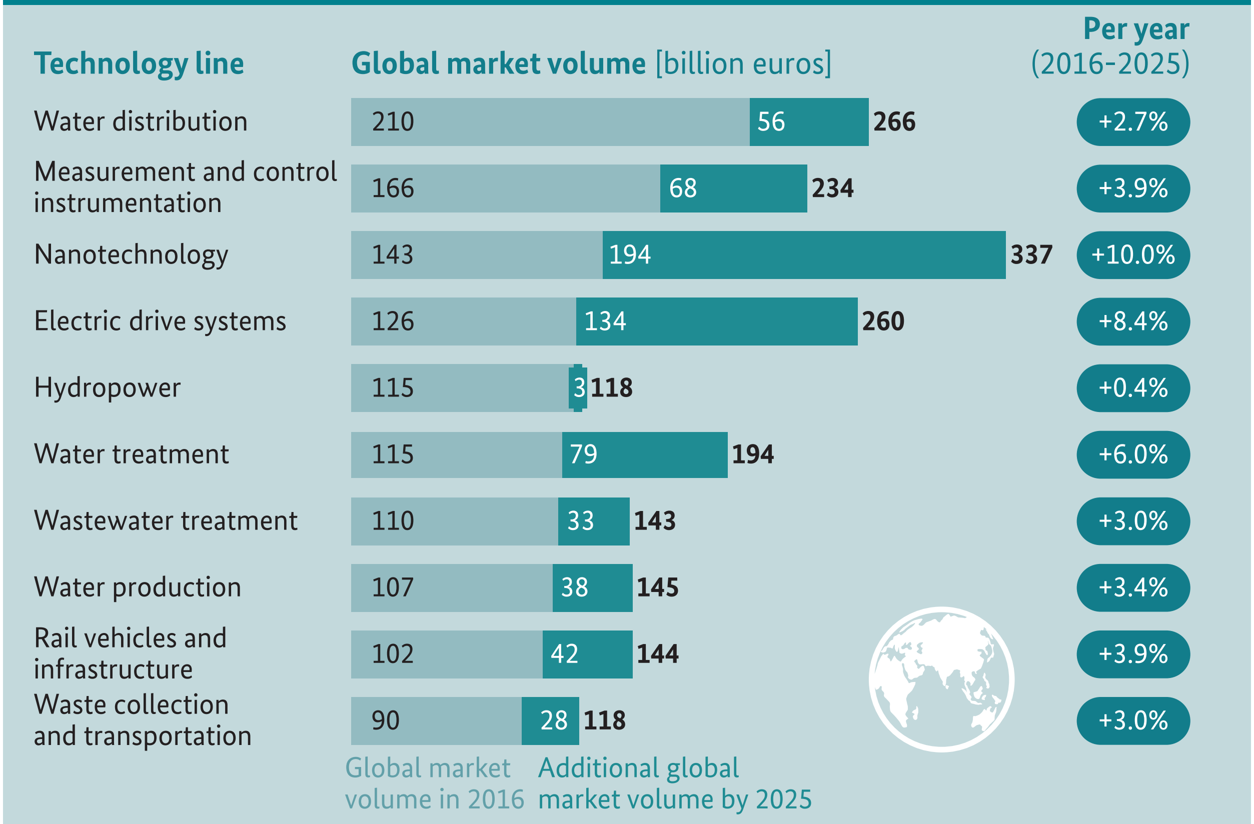
51 See Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA) (2015), page 8.
52 See Bayerisches Landesamt für Umwelt (2016), page 2.
53 Ibid.
54 See Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA) (2015), page 8.
55 See Bayerisches Landesamt für Umwelt (2016), page 3.
56 See Umweltbundesamt (2016e).

Leading technology lines: The top ten

This chapter has so far focused on the lead markets, their market segments and their technology lines. Our analysis was based on market volumes in 2016 and their forecast development through 2025. This segment now picks out ten specific technology lines from across the six green tech lead markets. Two criteria shaped our choices: a large share of the total global market volume for environmental technology and resource efficiency, and a relatively high average annual growth rate. As shown in Figure 39, these “top ten” technology lines together add up to a market volume of 1,284 billion euros – nearly 40 percent of the total green tech market volume. At the same time, relatively high growth rates lead us to conclude that these technology lines will continue to play a prominent role in the green markets of the world in the future.

It is immediately striking that five of the top ten technology lines – water distribution, water treatment, wastewater treatment, water production, and waste-water collection and transportation – all belong to the lead market for sustainable water management. This weighting bears clear testimony to the increasing importance of supplying water to a growing world population and dealing with an ever more acute water crisis.

Figure 39: Selected technology lines with large global market volumes in 2016 and fast growth rates (billion euros, average annual change 2016 to 2025 in percent)



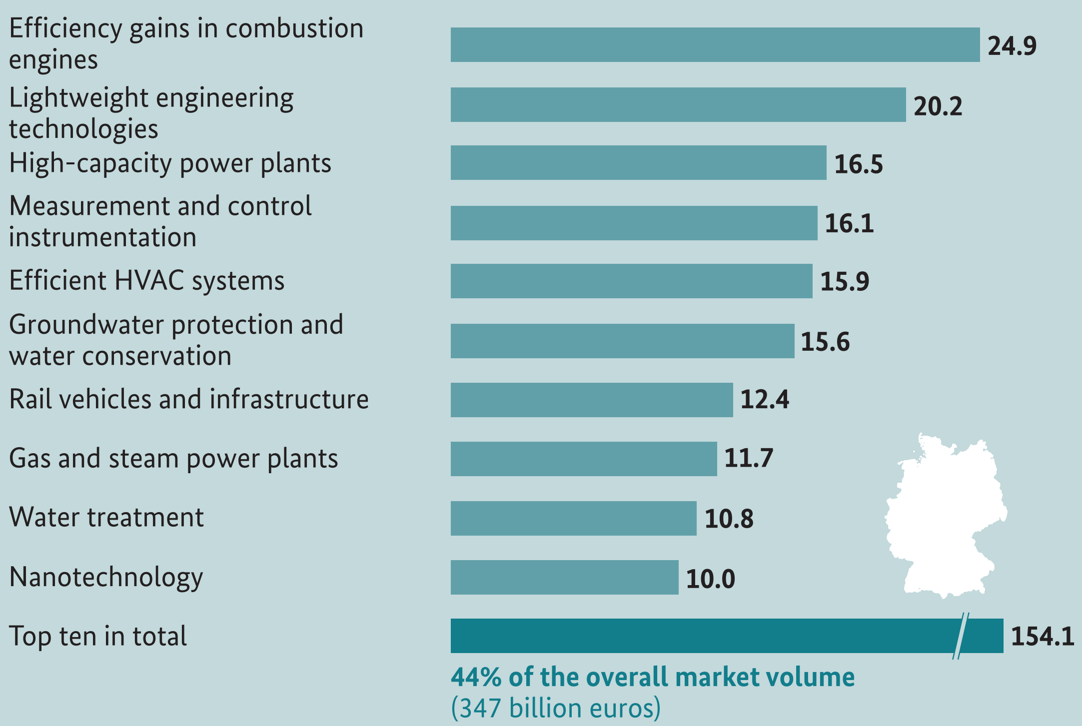
Source: Roland Berger (2017)

Germany: Efficiency gains in combustion engines – The technology line with the largest market volume

Breaking the green tech markets in Germany down to the level of technology lines produces the splits revealed in Figures 40 and 41. Figure 40 highlights the ten technology lines in the environmental technology and resource efficiency industry that have the largest market volume in Germany. Taken together, these technologies were worth 154.1 billion euros in 2016, accounting for 44 percent of the country's total green tech market.

The technology line efficiency gains in combustion engines leads the field in Germany with a market volume of 24.9 billion euros. This position mirrors the considerable importance the German automotive industry has long attached to developing efficient combustion engines. Second place in the rankings goes to lightweight engineering, which helps reduce fuel consumption and therefore also contributes to gains in automotive efficiency. This technology line has a German market volume of 20.2 billion euros. The fact that the technology line efficient heating, air-conditioning and ventilation systems has a market volume of 15.9 billion euros reflects a commitment to improving the energy efficiency of buildings. With a volume of 16.1 billion euros, measurement and control instrumentation is another important technology line in Germany's green tech industry.

Figure 40: The top ten technology lines in Germany by market size in 2016 (billion euros)



Source: Roland Berger (2017)

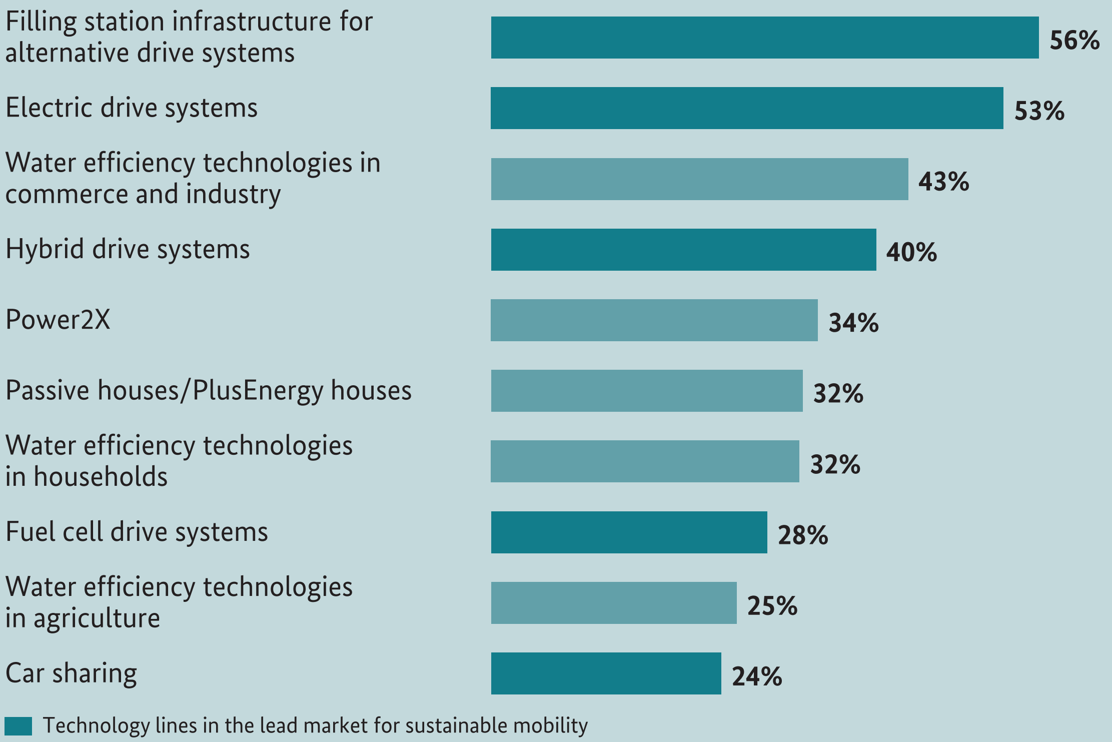
Figure 41 shows the top ten technology lines in the German green tech market in terms of average annual growth in the period from 2016 through 2025. It is immediately apparent that five of the fastest-growing technology lines belong to the lead market for sustainable mobility. Driving this growth is the transition to environmentally compatible, low-carbon mobility in the transport sector. The more vehicles with alternative drive systems (especially e-cars) are out and about on Germany's roads, the greater will be demand for the corresponding charging infrastructure. This consideration is driving extremely rapid development in the technology line filling station infrastructure for alternative drive systems, where average annual expansion of 56 percent is anticipated through 2025.

The market volume for electric drive systems will increase at a similarly vigorous pace. Average annual growth of 53 percent is projected for this technology through 2025. The technology line hybrid drive systems, too, will grow sharply – at an average annual rate of 40 percent, according to forecasts. In the market segment for alternative drive technologies, not only electric drive systems but also fuel cell drive systems have an important part to play. Through 2025, this technology line is predicted to grow at an average annual rate of 28 percent, albeit from a relatively small base volume of only 28 million euros in 2016.

Especially in conurbations, car sharing is establishing itself as an attractive link in the integrated mobility chain. More and more people are keen to use a car when they need one without necessarily owning one. This attitude is making them more open to car sharing offerings, with the result that more providers are actively targeting this market. The network of hire stations will thus become more tightly meshed in the future, driving a forecast average annual growth rate of 24 percent for this technology line through 2025.

Among the fastest-growing technology lines, the market segment for efficiency gains in water usage is likewise well represented. This segment's three technology lines deliver products, processes and services to promote the more efficient use of water resources in private households, commerce and industry, and agriculture. All three technology lines are set to develop very rapidly through 2025.

Figure 41: The top ten technology lines in Germany by growth, 2016 to 2025 (average annual change in percent)



Source: Roland Berger (2017)

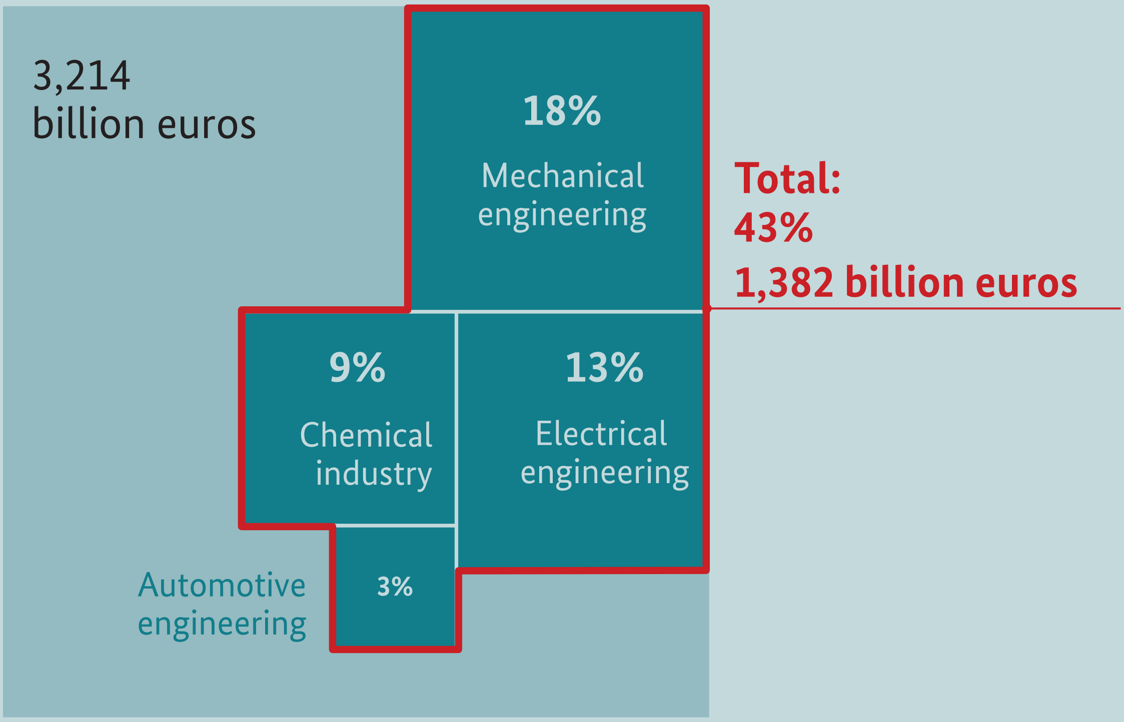
Close links between the green tech industry and other key industries

Blurred lines between themselves and other sectors are typical of cross-sector industries. That is equally true of environmental technology and resource efficiency, which overlaps with many key sectors such as mechanical engineering, the chemical industry, electrical engineering and automotive engineering. Both in Germany and on the international market, there are many companies that started out in one of these traditional key industries before adding green products, processes and services to their portfolio and diversifying into the green tech industry. While remaining firmly anchored in their original lines of business, these companies now also sell products and services that belong to the environmental technology and resource efficiency sector.

Figure 42 reveals the extent to which companies that originated in other industries beyond the remit of environmental technology and resource efficiency now also operate on the global green tech market. From the whole broad spectrum of key industries, electrical, mechanical and automotive engineering were analyzed together with the chemical industry for this purpose. The main reason for choosing these key industries is their tremendous importance to the German economy in general and to manufacturing in particular.[57] In 2016, automotive, mechanical and electrical engineering and the chemical industry together accounted for 43 percent of the world market for environmental technology and resource efficiency. Mechanical engineering had the largest share (18 percent), followed by electrical engineering (13 percent), the chemical industry (9 percent) and automotive engineering (3 percent). The point here is to illustrate the extent to which the green transformation has already made inroads into traditional key industries. As we can clearly see, environmental technology and resource efficiency products, processes and services are today of great importance to the portfolios of companies whose roots are outside the green tech industry.

Having looked in Figure 42 at the share of the global green tech market volume generated by firms from electrical, mechanical and automotive engineering and the chemical industry, Figure 43 shifts the focus to analyzing the market volumes of these four key

Figure 42: Traditional industries' share of the global market for environmental technology and resource efficiency in 2016 (percent)



Source: Roland Berger (2017)

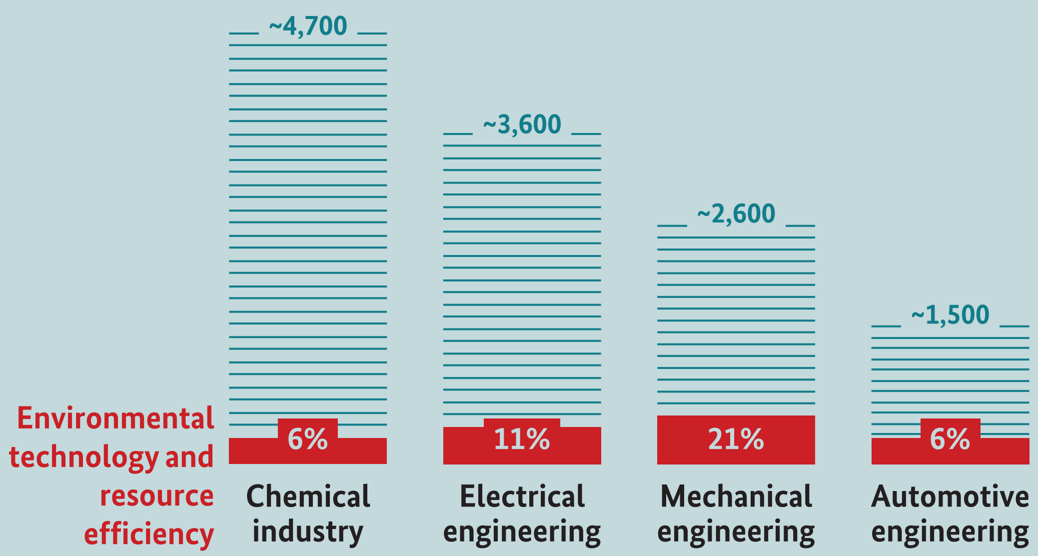
57 Combined sales of 969 billion euros mean that automotive, mechanical and electrical engineering and the chemical industry together account for roughly 69 percent of the total revenue posted by all of Germany's industrial companies. All in all, some 2.8 million people work in these four industries – approximately 58 percent of the country's entire industrial workforce. See Bundesministerium für Wirtschaft und Energie (2017e).

industries. The bar chart shows what percentage of the overall market volume in these four key industries is attributable to technology lines in environmental technology and resource efficiency. By highlighting the share of revenue earned with green products, processes and services, the chart demonstrates the importance of green tech to other branches of industry.[58]

Green tech plays an especially prominent role in mechanical engineering, accounting for 21 percent of the global market volume for this cross-sector industry. In electrical engineering, environmental technology and resource efficiency has an 11 percent share of the global market volume. Such figures underscore the considerable importance attached to green technology in the portfolios of companies rooted in these key industries. In other words, environmental technology and resource efficiency is firmly anchored in these traditional sectors.

When examining the links between the cross-sector green tech industry and other branches of industries, a glance at Germany's construction sector is similarly enlightening: Several green tech market segments – such as energy-efficient buildings – overlap with this sector. In 2016, construction and urban development segments of relevance to the environment had a total volume of 81 billion euros. That is equivalent to 21 percent of Germany's total construction volume (350 billion euros).

Figure 43: Environmental technology and resource efficiency's share of the global market volume in selected industries in 2016 (billion euros)



Source: Roland Berger (2017)

58 To avoid the danger of misinterpretations, please note the following: The fact that mechanical engineering's market volume is shown to include a 21 percent share of green technology says nothing about the environmentally friendly and low-carbon nature of those products and services that make up the remaining 79 percent of market volume. A green tech market volume of 21 percent means that this share of revenue from products, processes and services is earned with technology lines that, in keeping with the Roland Berger market model, are attributable to the market for environmental technology and resource efficiency.

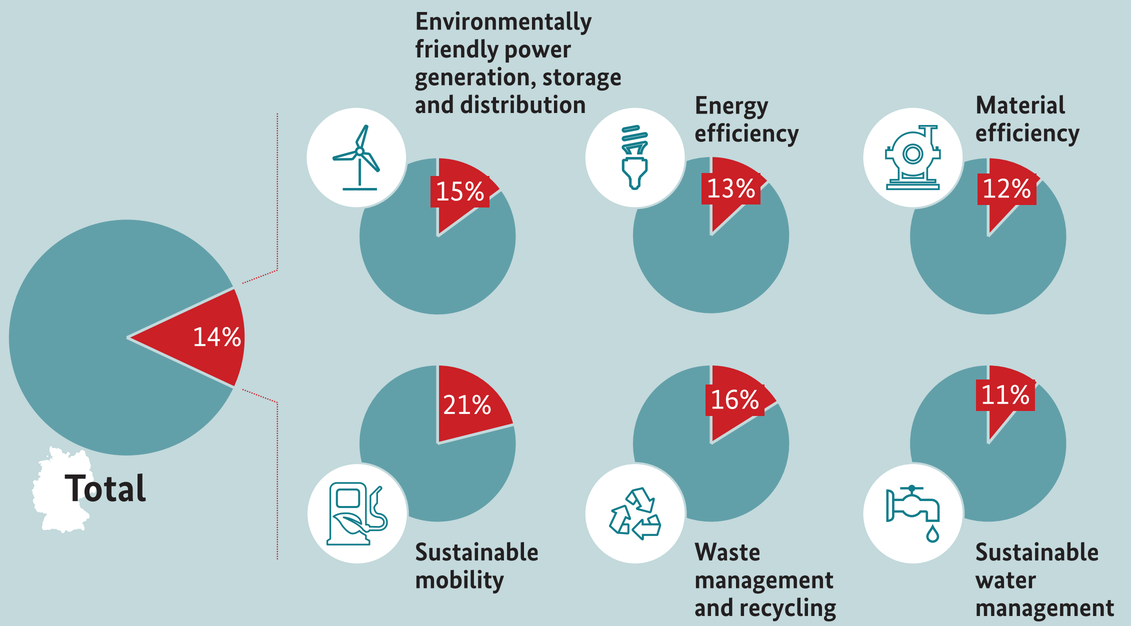
Environmental technology and resource efficiency made in Germany: Stimulus for the domestic economy

Positioning of German green tech firms on global markets

Green technology that bears the label "made in Germany" is much in demand on international markets. German providers have a 14 percent share of the global market for the cross-sector environmental technology and resource efficiency industry. Green tech companies from this country have thus successfully stabilized the strong international positioning they had already established in the past.[59] While the same global market share of 14 percent was also calculated in 2013, the individual lead markets' proportion of this global share has shifted slightly in the meantime. Between 2013 and 2015, the lead market for sustainable mobility boosted its global market share from 17 to 21 percent. In the same period, German providers of products, processes and services in the lead market for energy efficiency raised their share of the global market from 12 to 13 percent. In sustainable water management, German companies' 11 percent share of the global market remained unchanged.

Overall, Germany's green tech firms thus accounted for a 14 percent share of the global market volume in 2016. Germany's share of global economic output was 4.6 percent in the same year.[60] Juxtaposing these two figures shows that the German environmental technology and resource efficiency sector is clearly continuing to punch above its weight on international markets.

Figure 44: German companies' share of the global market for environmental technology and resource efficiency by lead market in 2016 (percent)



Source: Roland Berger (2017)

Figure 45 presents a more granular picture of German companies' positioning on the global markets. The global market shares enjoyed by selected technology lines are shown for each green tech lead market (see Figure 45).

59 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2015c), page 97.
60 See World Bank (2017).

Figure 45: German companies' global market share in selected technology lines across the green tech lead markets in 2016; development trend through 2025

Global market shares in 2016 and trend through 2025

	1 Env. friendly power gen., storage and distribution	2 Energy efficiency	3 Material efficiency	4 Sustainable mobility	5 Waste management and recycling	6 Sustainable water management
Lead market (average)	15% Down	13% Down	12% Down	21% Up	16% Unchanged	11% Down
Of which (selected technology lines)	Power2X 80% Down	Passive/Plus-Energy houses 60% Down	Processes in the chem. industry 15% Unchanged	Efficiency gains in comb. engines 50% Up	Energy recovery 35% Down	Innovative sanitation syst. 25% Down
	Wind power (offshore) 25% Up	HVAC 30% Down	Nature and landscape cons. 15% Down	Biomethane 35% Up	Mechanical recycling 25% Up	Water treatment 15% Up
Projected change in Germany's share of the global market by 2025	Wind power (onshore) 10% Unchanged	Measurement and control instr. 15% Down	Biotechnology 10% Up	Car sharing 15% Down	Feedstock recycling 5% Up	Water distribution 10% Unchanged
↑ Up → Unchanged ↓ Down	Waste heat recovery 5% Up	Green IT 5% Down	Composite materials 10% Up	Bioethanol 5% Down	Landfill 5% Up	Energy mgmt. in WWTPs 10% Up

Source: Roland Berger (2017)

Environmental technology and resource efficiency – Stimulus for growth and employment

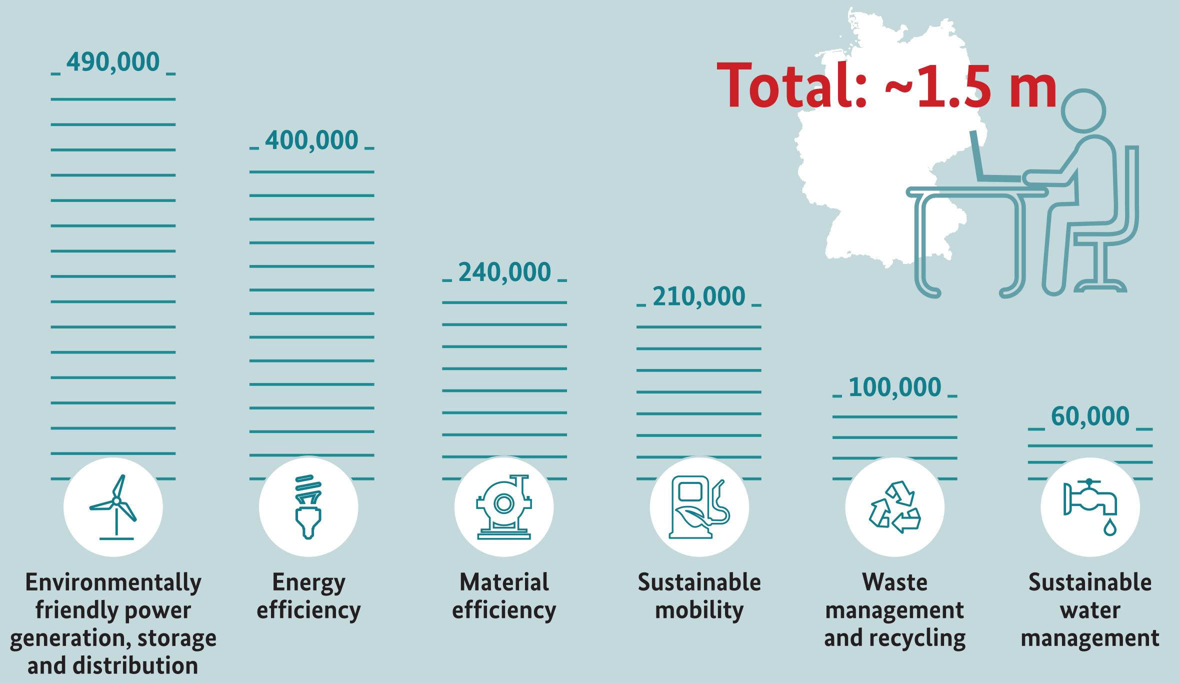
Green tech's importance to Germany is reflected in this industry's share of gross domestic product (GDP). In 2016, environmental technology and resource efficiency contributed 15 percent to the country's economic output. This cross-sector industry thus has a heavier economic weighting in Germany than on a global level: Environmental technology and resource efficiency makes up just 5 percent of the world's total economic output.

Employment figures are an indicator of the powerful macroeconomic role played by environmental technology and resource efficiency in Germany.
Around 1.5 million people in Germany worked in the six green tech lead markets in 2016 (see Figure 46). This number only includes employees at companies specifically assigned to one of the defined lead markets.
Our calculation of these employment figures is based partly on the market analysis for technology lines in Germany outlined in the previous sections, and partly on the findings of our survey of 2,650 companies in the environmental technology and resource efficiency industry.

Our market analysis calculates the size of each of the six lead markets in 2016 and their likely growth between now and 2025. It is rooted in a study of more than 120 individual technology lines grouped together under the heading of environmental technology and resource efficiency.

The findings of the company survey contain statements made by players in each of the six lead markets about the focus of their activities, their sales revenue and the number of people they employ. The respondent companies also cite their growth expectations. For each lead market, this data is then used to calculate "average sales per employee". Combining the two analyses also makes it possible to extrapolate the number of employees in the overall market for environmental technology and resource efficiency.

Figure 46: People employed in environmental technology and resource efficiency in Germany in 2016



Source: Roland Berger (2017)

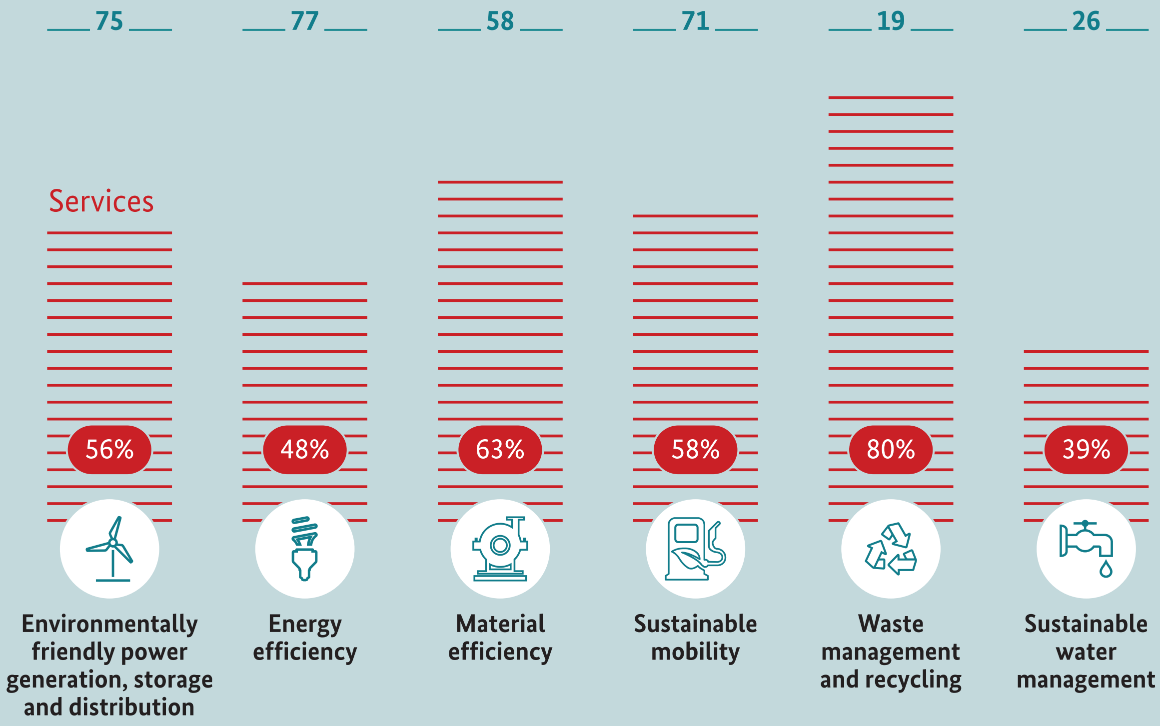
Service intensity in the green tech industry

The process known as tertiarization – the structural transition from an industrial to a service-based society – has long since taken hold of environmental technology and resource efficiency, too. The trend is reflected in the growing service intensity in the six green tech lead markets.

Service intensity denotes the contribution made by services to the total market volume in environmental technology and resource efficiency. Green services are playing a vital role in driving the transformation to a sustainable economy. For example, an energy contractor who advises customers on the planning, financing and operation of energy systems helps improve energy efficiency and, hence, reduce CO_2 emissions. Green tech service providers can boost market volumes by stimulating demand – one example being project developers who use green technologies to implement their plans. Environmental services promote the adaptation of existing business models and encourage the development of new green models. Another example would be electric filling stations that can recharge the batteries of electric cars in a variety of ways.

Figure 47 shows both the total market volume for each lead market – comprising production, plant engineering and services – and the service intensity in each of these markets. The latter is represented as services' share of the lead market's overall volume. A service intensity ratio of 80 percent for waste management and recycling stands out. The reason for this immensely high figure is the large proportion of services provided in the market segment for waste collection, transportation and separation. In most cases, waste collection and waste transportation are still neither automated nor decentralized.

Figure 47: Market volume for environmental technology services and service intensity in the six lead markets in Germany in 2016 (billion euros, service intensity in percent)



Source: Roland Berger (2017)

5

Green tech providers up close: Insights into a growing industry

First-hand status report

What is the current mood among German providers of environmental technology and resource efficiency? The answers to this question paint a multi-faceted picture of this branch of industry, based essentially on an online corporate survey. The findings affirm the forceful role played by medium-sized companies, Germany's innovative strengths and the international orientation of its green tech industry.

At a glance

Medium-sized companies play a powerful, formative role in Germany's environmental technology and resource efficiency sector. Roughly 90 percent of the country's green tech players are small and medium-sized enterprises (SMEs). The lead market for environmentally friendly power generation, storage and distribution, on the other hand, is populated by a comparatively sizeable number of medium-sized and large companies.

Employment figures likewise reflect the prominent role played by SMEs in environmental technology and resource efficiency. About 44 percent of the companies in this cross-sector industry employ ten people at most. More than a quarter of green tech companies employ over 50 people. Only 6 percent have more than 500 people on their payroll.

German providers of environmental technology and resource efficiency still see Europe and China as their most important target markets, although they expect Russia too to become more significant as a sales market for "green tech made in Germany". Brazil, India, China, the Middle East, Africa and North America will also play an increasingly important role as export markets.

German companies' capabilities in robotics, digital production, virtual systems and system solutions will be a key success factor on the international green tech markets. In environmental technology and resource efficiency, innovation is increasingly being driven by systemic developments and less by isolated innovations.

This Chapter outlines the supply side of the market for environmental technology and resource efficiency in Germany. It thus complements the analysis provided in Chapter 4, which focuses on the demand side of national and international markets.

Our portrait of the industry is based essentially on analysis of a web-based company survey conducted from July through November 2016 on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The responses supplied in the online questionnaire were channeled into the database that contains more than 2,500 company profiles and lays the foundation for the pictured painted in this Chapter.

Our profile of the industry also documents a number of parameters and trends distilled from the findings of the company survey: revenue structure, employee structure, R&D spending relative to sales revenue (R&D intensity), portfolio, and an assessment of both the current business situation and future prospects.

Environmental technology and resource efficiency players at a glance: Sales revenue, workforce, portfolios, innovations

Medium-sized companies play a powerful, formative role in Germany's environmental technology and resource efficiency sector. Roughly 90 percent of the country's green tech players are small and medium-sized enterprises (SMEs). Bonn-based SME research organization Institut für Mittelstandsforschung (IfM) defines small and medium-sized enterprises as companies with annual revenues of up to 50 million euros and no more than 500 employees.[1] Measured in terms of revenues, SMEs make up by far the largest proportion of German players in environmental technology and resource efficiency. This breakdown in the green tech industry differs only marginally from the structure of the German economy as a whole: Companies that post annual revenues of up to 50 million euros account for 99 percent of all companies in Germany.[2]

1 See Institut für Mittelstandsforschung (2017).
2 Calculated based on data from Germany's Federal Statistical Office. See Statistisches Bundesamt (2017b).

Sales revenue: Current status and future expectations

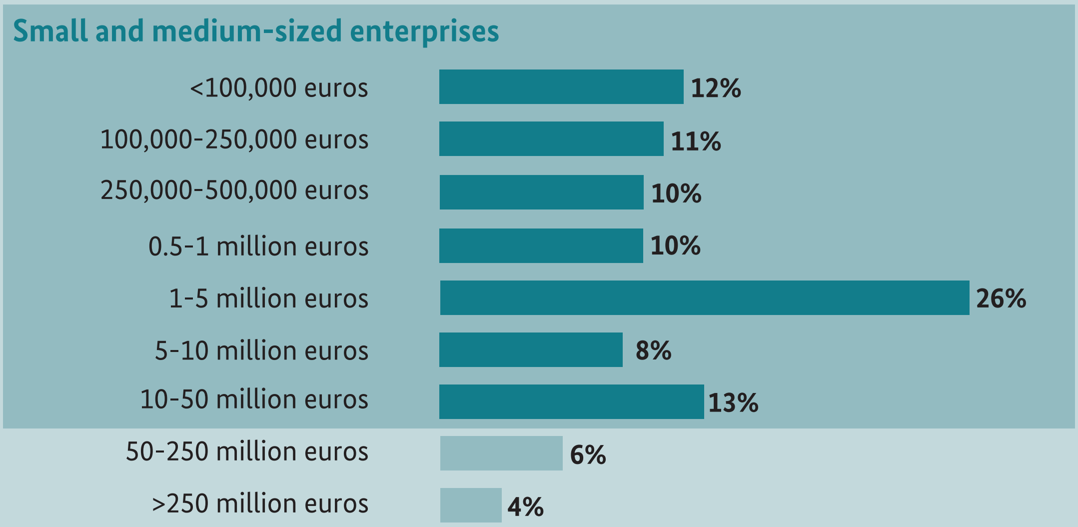
About a quarter of all green tech companies in Germany report annual sales revenue of between 1 million euros and 5 million euros (see Figure 48). Companies that post sales of between 1 million euros and 50 million euros make up 47 percent of the entire sector. As shown in Figure 48, 43 percent of green tech players turn over less than 1 million euros a year and are classed as small firms.

The sales revenue generated by the individual players in Germany's environmental technology and resource efficiency market is a key indicator in our analysis of this industry. The average green tech company in this country reports annual revenue of 25 million euros. Figure 49 provides an overview of individual companies' annual revenue based on their "lead market focus", which, in this context, is the lead market that accounts for the largest proportion of their sales.

Companies that focus on the lead market for environmentally friendly power generation, storage and distribution generate annual revenue of 30 million euros on average – substantially more than firms that focus on other green tech lead markets. This upside discrepancy is due to the structure of this particular lead market: More medium-sized and large companies operate in environmentally friendly power generation, storage and distribution than in the other lead markets.

To genuinely capture the mood in the environmental technology and resource efficiency sector, we asked players in the industry about their revenue expectations for the years ahead. Between now and 2021, green tech companies in Germany anticipate average annual sales growth of 9.8 percent (see Figure 50).

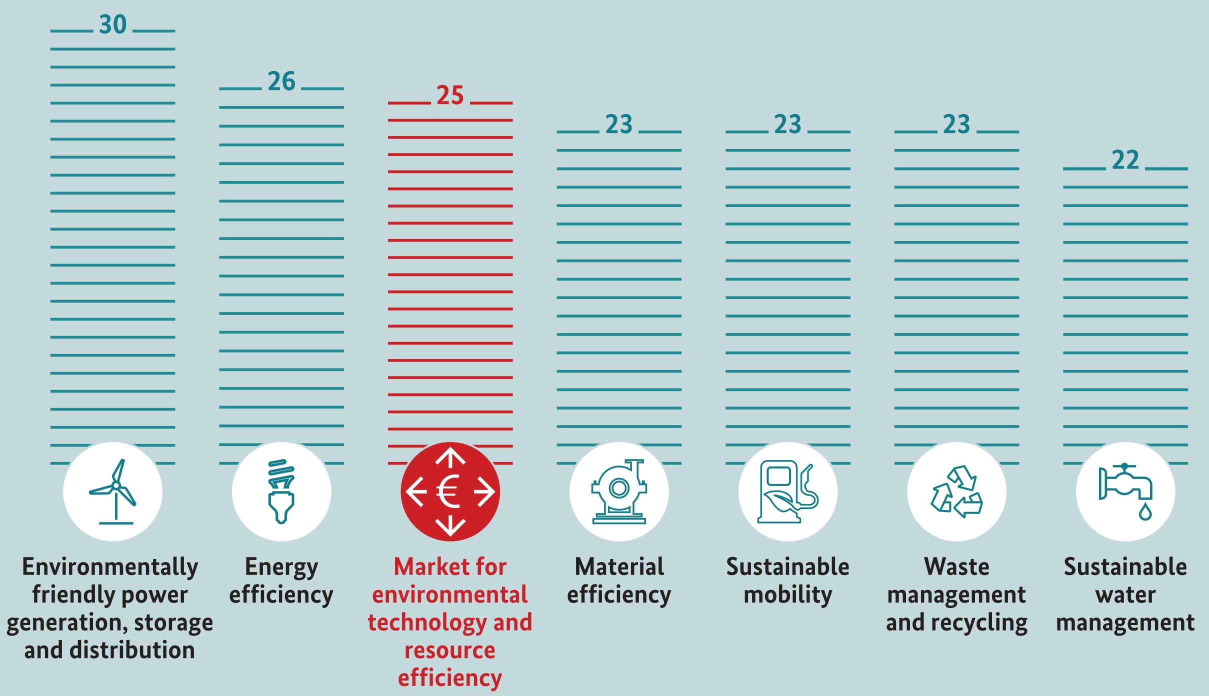
Figure 48: Breakdown of companies by sales volume (percentage of mentions)



Source: Company survey (2,469 responses), Roland Berger (2017)

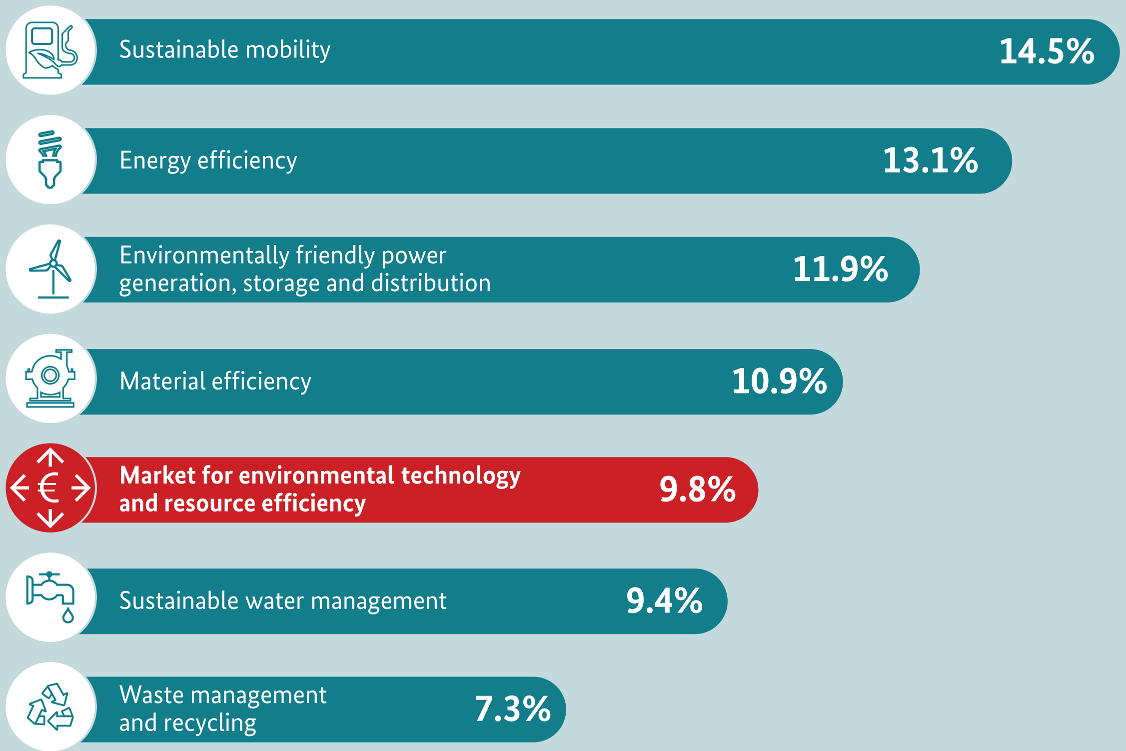
The fastest growth is expected by companies that focus on the lead market for sustainable mobility: They expect to see sales increase by an annual average of 14.5 percent through 2021. Companies whose focus is on the lead market for energy efficiency have similarly high expectations: On average, they expect sales to grow by 13.1 percent per annum between now and 2021. Firms with a focus on the lead market for waste management and recycling expressed more cautious projections, anticipating annual sales growth of 7.3 percent. This perception acknowledges the fact that waste management and recycling already constitutes a fairly mature market in Germany.

Figure 49: Average annual revenue per company by lead market focus (million euros)



Source: Company survey (1,977 responses), Roland Berger (2017)

Figure 50: Average expected sales growth per company through 2021 by lead market focus (percent)

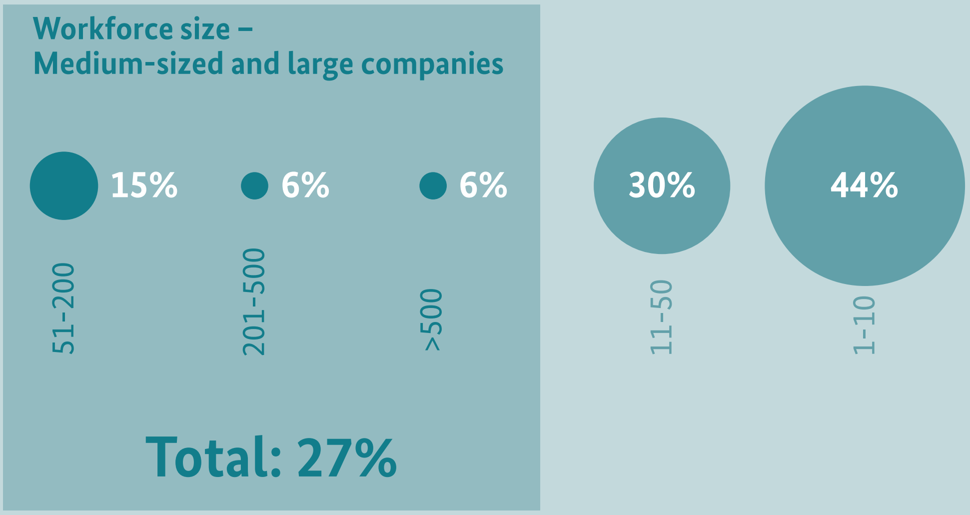


Source: Company survey (1,977 responses), Roland Berger (2017)

Employee figures: Current status and planning projections

The breakdown of companies by size of workforce (or headcount) is another key parameter that helps us understand the structure of the environmental technology and resource efficiency sector. About 44 percent of the companies in this cross-sector industry employ ten people at most (see Figure 51). This figure reflects the fact that the green tech industry is awash with small companies. Providers of engineering and consulting services in particular generally have only a handful of employees. More than a quarter of green tech companies employ over 50 people. Only 6 percent have more than 500 people on their payroll.

Figure 51: Companies by workforce size (percentage of mentions)



Source: Company survey (2,584 responses), Roland Berger (2017)

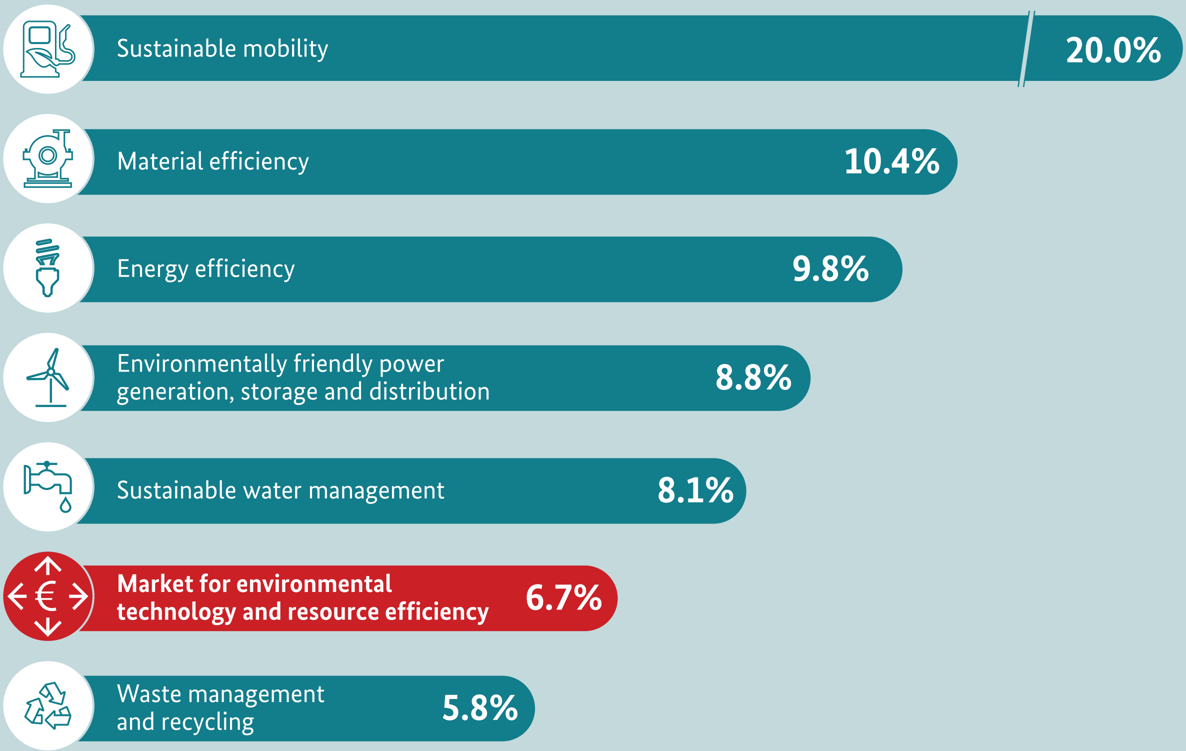
Besides assessing sales growth, headcount trends are another useful indicator to help capture the mood of players in the green tech industry. Expected workforce growth was therefore another topic addressed in the company survey. Between now and 2021, companies in the environmental technology and resource efficiency industry expect to see their headcount increase by an average of 6.7 per year (see Figure 52).[3] As with sales projections, companies with a focus on the lead market for sustainable mobility again have the highest expectations in the green tech industry with regard to the employment trend. They expect the workforce to increase by an annual average of 20 percent. By contrast, the expectations of companies focused on the lead market for waste management and recycling are far more modest: These firms anticipate average annual headcount growth of 5.8 percent between now and 2021.

The difference in expectations between firms focused on sustainable mobility at one end of the spectrum and firms focused on waste management and recycling at the other end lines up with sentiments we saw earlier in sales expectations, and with the completely different situations from which the two lead markets are moving forward today: Players in the lead market for sustainable mobility expect to see forceful growth, triggered to a large extent by expansion in alternative drive technology in general and e-mobility in particular. Dynamic development in this lead market is gaining further impetus from new players who, alongside the automotive incumbents, are presenting innovative mobility solutions. Examples include Google's approach to autonomous driving and Tesla in the field of battery development.

3 Growth not weighted by revenue.

This clash of Titans new and old is bringing forth new offerings that are both driving innovation and expanding the lead market for sustainable mobility. On the other hand, companies with a focus on waste management and recycling are operating in what is already a much more mature market segment where virtually no new international players are stepping into the ring – a situation that tends to inhibit both growth and the passion to innovate in this lead market. The different conditions that prevail in these two lead markets are also mirrored in the intensity of research and development (see Figure 54). This barometer of innovative vitality stands at 3.4 percent for sustainable mobility, but just 2.4 percent in waste management and recycling.

Figure 52: Average annual workforce growth projections through 2021 by lead market focus (percent)



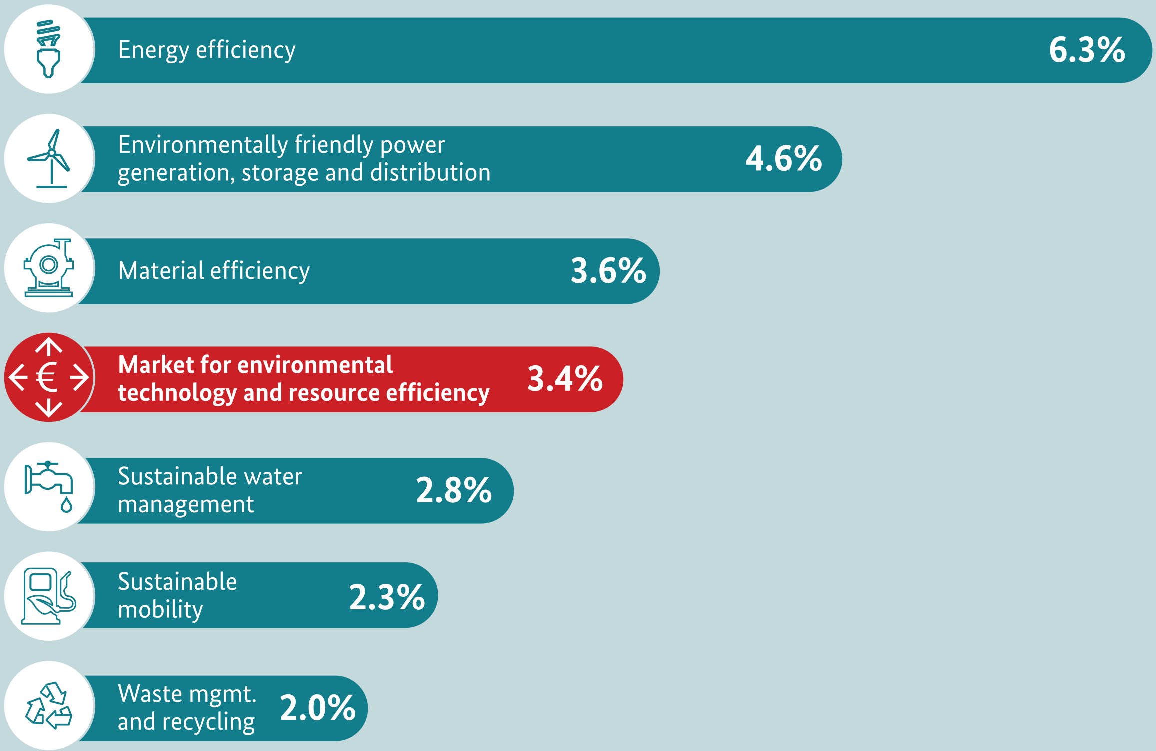
Source: Company survey (2,135 responses), Roland Berger (2017)

Productivity on the up

In the period from 2016 through 2021, Germany's green tech players expect productivity to improve by 3.4 percent[4] on average across all lead markets (see Figure 53). Productivity is the ratio of sales revenue to the number of employees. We have therefore condensed companies' expectations with regard to sales and employment into aggregate figures for expected productivity growth in the six lead markets.

4 Growth weighted by revenue.

Figure 53: Average annual productivity gains through 2021 by lead market focus (percent)



Source: Company survey (1,824 responses) , Roland Berger (2017)

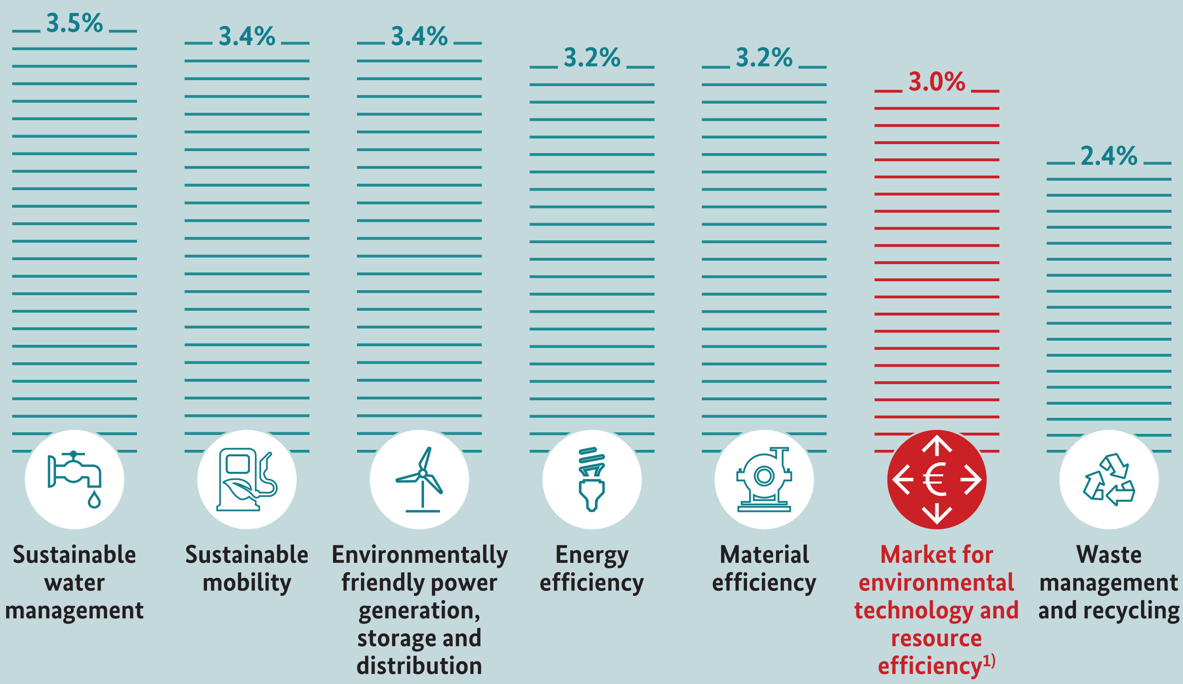
Research and development spending

Depending on the lead market in which they operate, Germany's green tech companies invest between 2.4 and 3.5 percent of their sales revenue in research and development (R&D). For green tech players, the average R&D intensity – the proportion of total sales revenue that is invested in research and development – is 3.0 percent (see Figure 54). R&D activities provide powerful stimulus for productivity and growth and can therefore be seen as an indicator of rapid development. To put the 3.0 percent average R&D intensity in environmental technology and resource efficiency into perspective, it is useful to cast a glance at other branches of industry and at the economy as a whole. OECD classifications position the green tech industry in the medium high-technology segment, which is where the OECD sees industries with an average R&D intensity of between 2 and 5 percent. Other industries in this category include mechanical, automotive and electrical engineering, for example. The OECD puts industries with R&D spending of at least 5 percent in the category high technology, while an R&D intensity of 0.5 to 2 percent assigns an industry to the medium low-technology sector. Deviating slightly from these classifications, the following definitions apply for Germany: The high-technology segment contains industries with an R&D intensity of over 7 percent, whereas industries with an R&D intensity of between 2.5 and 7 percent belong in the medium high-technology segment. It is important not to misunderstand this model, however: R&D intensity should not be taken as a general verdict on the quality of an industry's innovative prowess. Even medium low-technology industries have successful companies with a high intensity of research and development.[5]

Looking at research and development expenditure in the six different lead markets, it is noticeable that companies focused primarily on sustainable water management have the highest average R&D spending of all, at 3.5 percent of sales revenue. With an average R&D intensity of 2.4 percent, waste management and recycling is the only lead market to fall below the industry average of 3.0 percent.

5 See Hüther, Michael (2015).

Figure 54: Average research and development spending per company by lead market focus (percent)



1) The average figures also factor in companies that focus on a different lead market, several lead markets or no lead market.

Source: Company survey (1,760 responses), Roland Berger (2017)

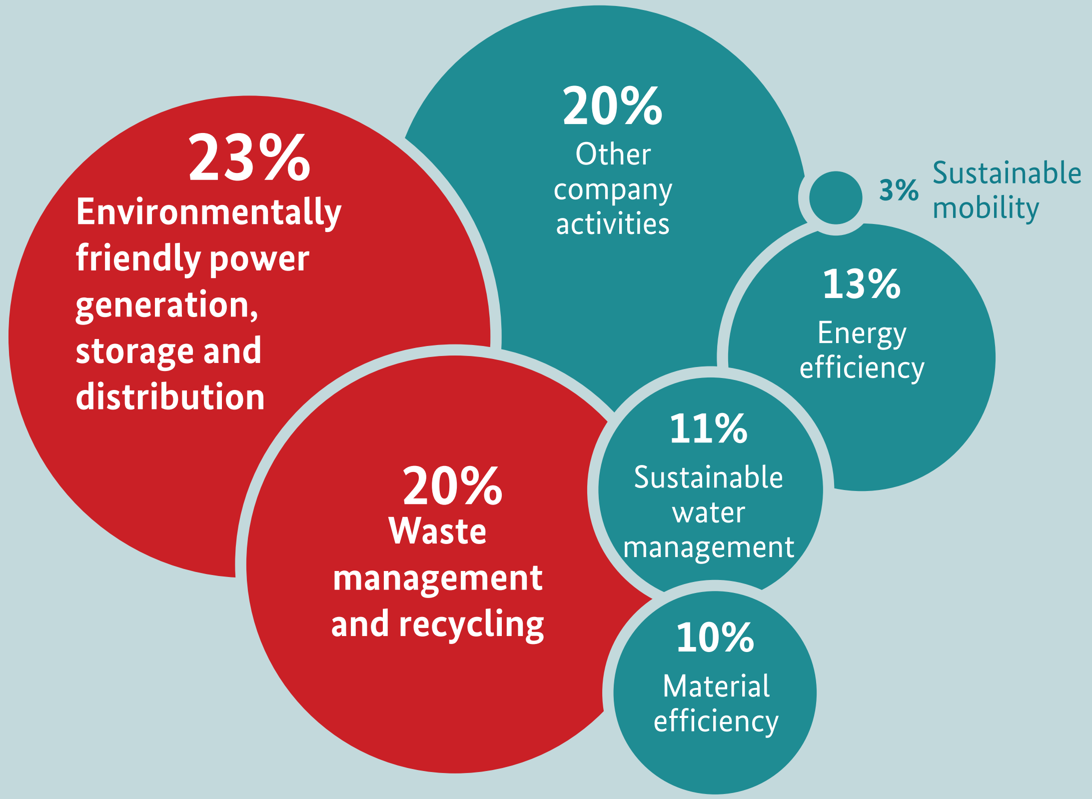
Green tech company portfolios: Knowledge-intensive services play a lead role

When analyzing the structure of supply in the environmental technology and resource efficiency industry, it is important to identify the lead markets in which green tech companies generate the bulk of their sales. This issue was addressed in the company survey, which found that 43 percent of the total volume for all participants is generated in the lead market for environmentally friendly power generation, storage and distribution and the lead market for waste management and recycling (see Figure 55). The lowest contributions to the total revenue volume are made by the lead markets for material efficiency (10 percent) and sustainable mobility (3 percent).

The survey's findings with regard to companies' positioning along the value chain highlight the innovative strength of the environmental technology and resource efficiency sector. The fact that more than a third of the respondent companies provide R&D services comes as further evidence that environmental technology and resource efficiency is a genuinely knowledge-intensive and technology-oriented industry.

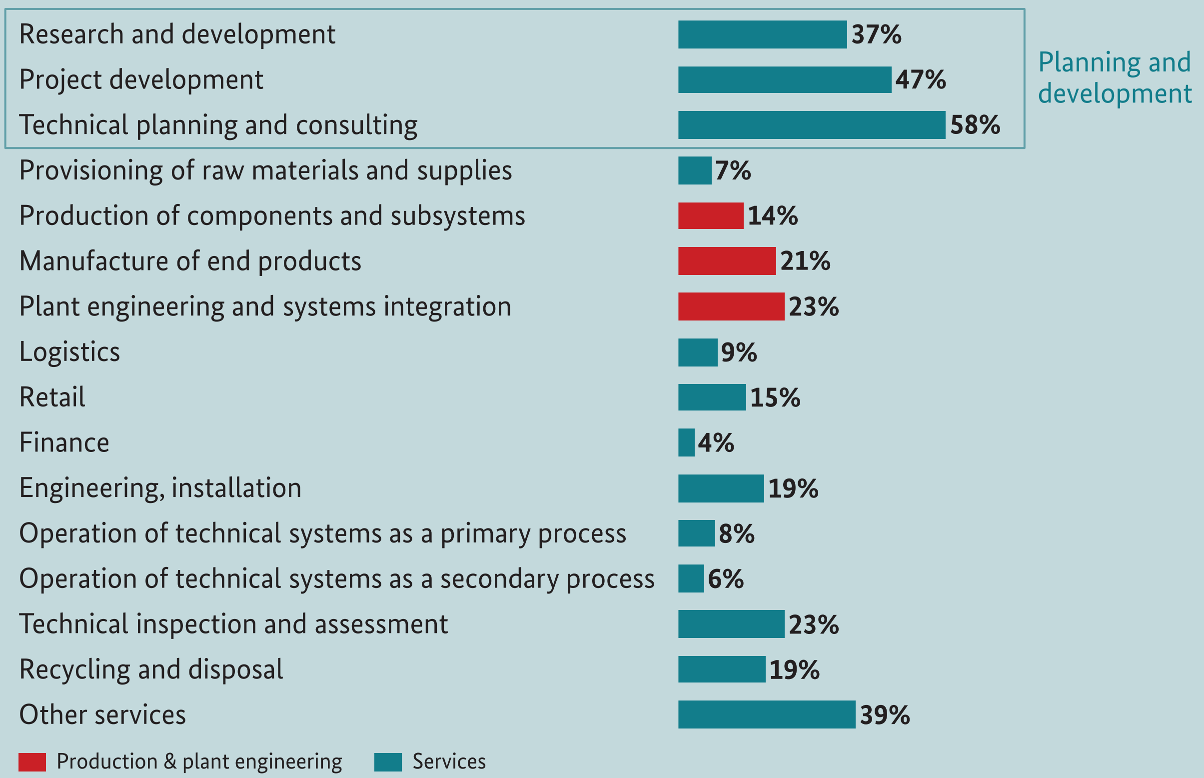
The green tech players that took part in the company survey are spread across the entire value chain (see Figure 56). The vast majority of respondent companies said they provide services. Fewer mentions were given to production and plant engineering. Planning and development activities are very heavily represented in the portfolio, in the categories technical planning and consulting, project development and research and development. This finding is indicative of the large number of engineering and consulting offices that populate the green tech industry.

Figure 55: Breakdown of companies' total sales volume across the lead markets[6] (percent)



Source: Company survey (2,703 responses), Roland Berger (2017)

Figure 56: Portfolio of services along the value chain (percentage of mentions)



Source: Company survey (2,703 responses), Roland Berger (2017)

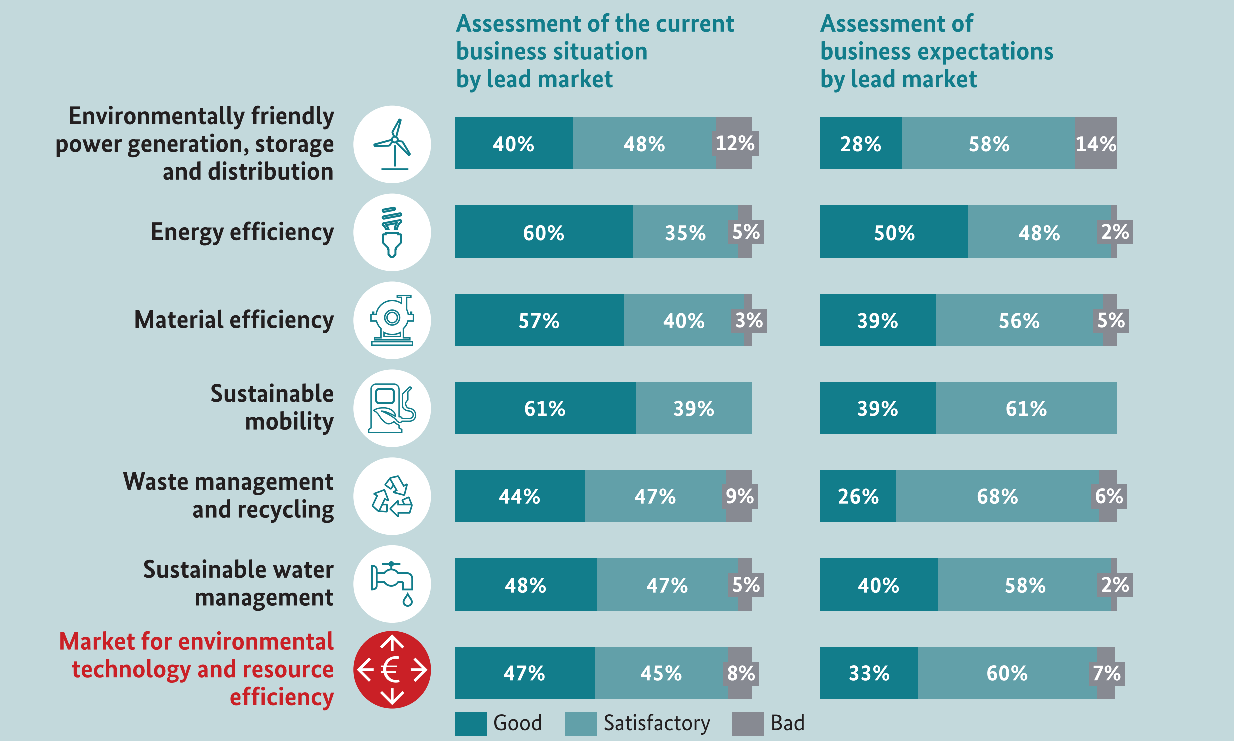
6 This chart is based on the answers given by companies that completed the online questionnaire in our web-based company survey.

Business situation and business expectations in Germany's green tech industry

The mood in Germany's green tech industry is rather patchy. Irrespective of the lead market in which they operate, nearly half of the respondent firms (47 percent) rate their current business situation as "good". 45 percent see it as "satisfactory", while 8 percent regard their business situation as "bad" (see Figure 57).

Looking ahead to the near future, a picture of cautious optimism emerges. One third of respondent companies across all lead markets believe that their business situation will improve through 2021. 60 percent expect their business situation to remain unchanged, and only 6 percent expect it to deteriorate (see Figure 57). The upbeat assessment of their current situation and the confidence about future prospects in evidence among companies focused on the lead market for energy efficiency aligns well with the considerable importance attached to energy efficiency in the context of mitigating climate change. The EU's energy policy motto "Efficiency first" gives providers of efficiency solutions good reason to be optimistic. At the same time, it is conspicuous that companies focused on the lead market for environmentally friendly power generation, storage and distribution are comparatively cautious in their view of both the current situation and medium-term business development. This stance reflects the situation on international markets, where competition and cost pressures are growing. Germany's photovoltaics industry has ceded global market share to Chinese players in recent years. Now, the fear is that similar developments could unfold in the wind power segment.

Figure 57: Assessment of business expectations by lead market



Source: Company survey (2,024 responses), Roland Berger (2017)

A business climate index calculated as part of our industry survey serves as a barometer, gauging the mood among green tech companies in Germany. Companies' assessment of the current situation and their expectations for the near future are both factored into calculation of the index. Derived from data for the respective year, the index is thus produced by combining two categories: business climate ("assessment of the current business situation") and business expectations. The industry-wide index is plotted on a scale from 0 to 100. The maximum (100) would indicate that every company rated its current business situation as "good" and its future business outlook as "more favorable".

Compared to recent years, the business climate index for environmental technology and resource efficiency slipped noticeably in 2016. Another significant fact is that the business climate index figures for the green tech lead markets are tending to lag behind the trend in the ifo business climate index for the economy as a whole.[7] In light of the fast pace of development on the international environmental technology and resource efficiency markets, this rather pessimistic attitude on the part of Germany's green tech providers appears astonishing at first glance. That said, there are two main reasons for their skepticism: (1) Given the growing number of foreign competitors who are likewise fighting for a share of the world's green tech markets, many German players are uncertain whether and to what extent they will indeed benefit from rising demand for green products, processes and services. (2) Various political flashpoints and armed conflicts (such as those in Syria and eastern Ukraine) as well as the European Union's own Brexit-related crisis are undermining confidence in the ability of international (climate) policy to genuinely stoke growing demand for green tech products in the years ahead. This phenomenon is not restricted solely to investment in environmental technology and resource efficiency, however. Other industries too are no strangers to the negative correlation between uncertainty and companies' propensity to invest: "In recent year, uncertainty has been a common theme in everything that has happened in the global economy and financial markets," according to a study by Deutsche Bank Research.[8] It is nevertheless true that the subjective element of expectations plays an especially pronounced role in the business climate index for environmental technology and resource efficiency. Looking at green tech companies' assessment of sales development and workforce size (see page 99; 101), the mood is less bleak than the business climate index might initially lead one to believe.

Detailed analysis shows that the business climate index has shifted into reverse for all green tech lead markets. The average index across all lead markets is 14 points lower than the figure for 2014. At first glance, this seems to contradict expectations with regard to sales development and increasing workforce sizes (see page 99; 101). One explanation for this discrepancy between the snapshots taken in 2014 and 2016 could be the changed political conditions that now prevail. For example, the reform of Germany's Renewable Energy Law has now altered the funding landscape for renewable energy systems. Moreover, given the tense situation with regard to public finances in major European countries, it is questionable whether we will ever see a rerun of the stimulus packages launched in the wake of the 2008/2009 economic and financial crisis – packages that covered many activities conducive to the development of a low-carbon infrastructure.

7 Produced by the ifo economic research institute, the ifo index has since 1972 been calculated regularly based on the business situation and business expectations of around 7,000 companies in manufacturing, construction, wholesale and retail.

8 See Deutsche Bank Research (2017), page 2.

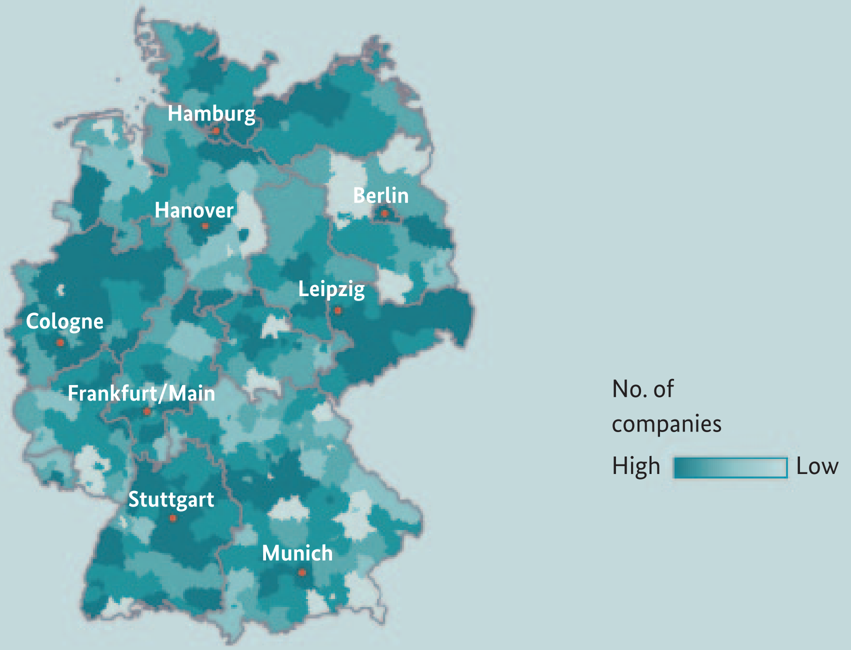
Different angles on Germany's green tech industry: Companies' geographic distribution

Our analysis of the green tech players who took part in the web-based company survey, their economic indicators and the location of their headquarters made it possible to draw a map of the industry. This map clearly highlights the regions where green tech has a substantial footprint. An initial overview (see Map 1) reflects an even spread of companies throughout Germany. While the density of green tech companies is particularly marked in conurbations, players in the cross-sector industry for environmental technology and resource efficiency also have a presence in more rural districts. A large number of green tech companies are, for example, based in Schleswig-Holstein and Mecklenburg-West Pomerania. A different picture emerges if one singles out only those environmental technology and resource efficiency firms that are positioned in the manufacturing industry: In this case, those administrative districts with a high density of industry are home to the largest number of green tech companies. Leading the field on this score are the regions around Munich, Stuttgart, Hanover, Dresden and Chemnitz (see Map 2).

Variations in the individual lead markets come more sharply into focus if the sales volume for green tech companies is broken down by administrative district. Decentralization is apparent above all in the lead market for waste management and recycling, which is typically characterized by a very high service intensity. By contrast, the activities of both large corporations and small firms in the lead market for sustainable mobility are mostly clustered around automotive production hubs or in areas with a high urban density, where services such as car sharing and charging infrastructures can best be made available.

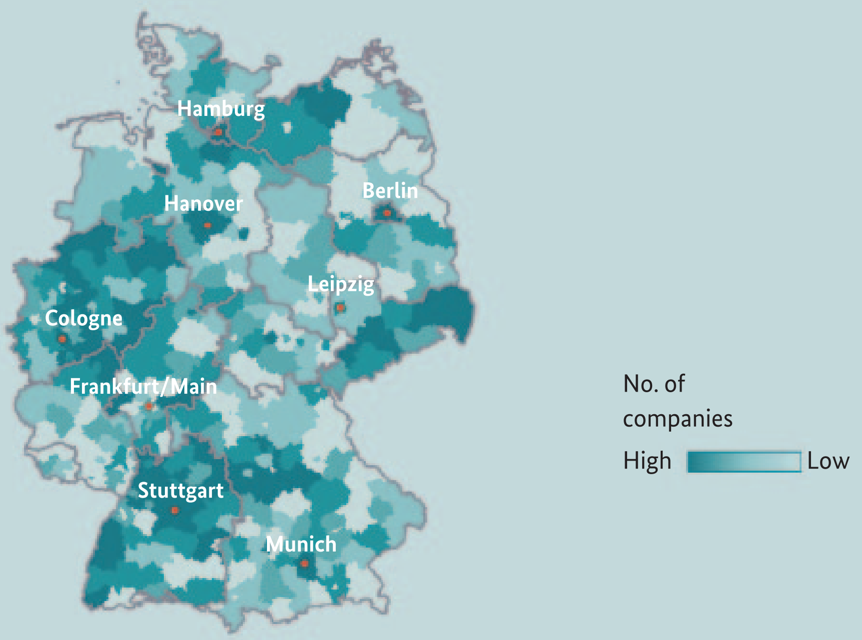
Green tech companies with a much stronger focus on exports normally tend to be highly innovative players. High concentrations of these companies are often found at prominent knowledge hubs with large universities and research institutes. To compete in the international arena, small, innovative firms and large corporations alike need a tightly meshed network of research, development and production. This is most clearly visible in the lead market for environmentally friendly power generation, storage and distribution and the lead market for sustainable water management.

Map 1: Regional distribution of companies in the market for environmental technology and resource efficiency, by administrative district[9]



Source: Company survey (2,701 responses), Roland Berger (2017)

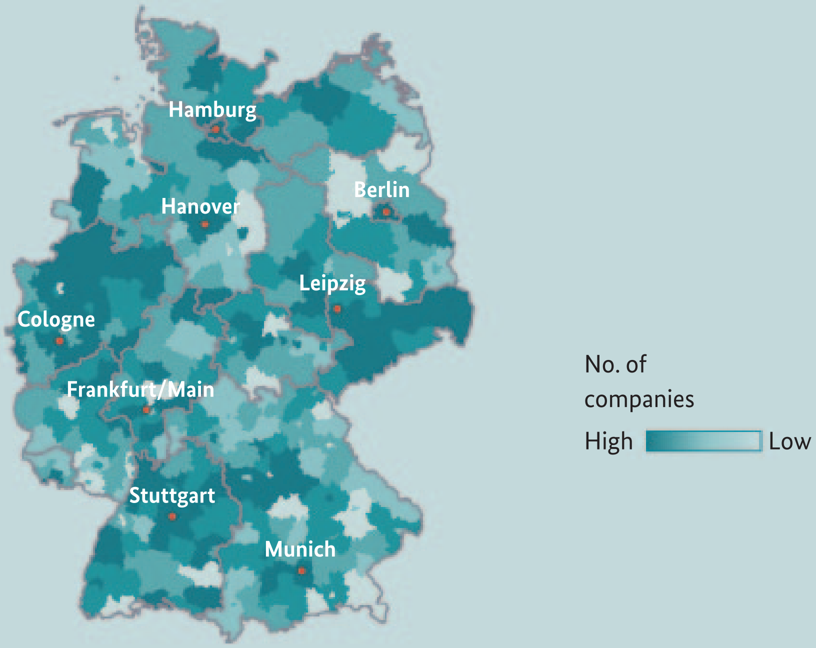
Map 2: Regional distribution of manufacturing companies in the market for environmental technology and resource efficiency, by administrative district



Source: Company survey (1,021 responses), Roland Berger (2017)

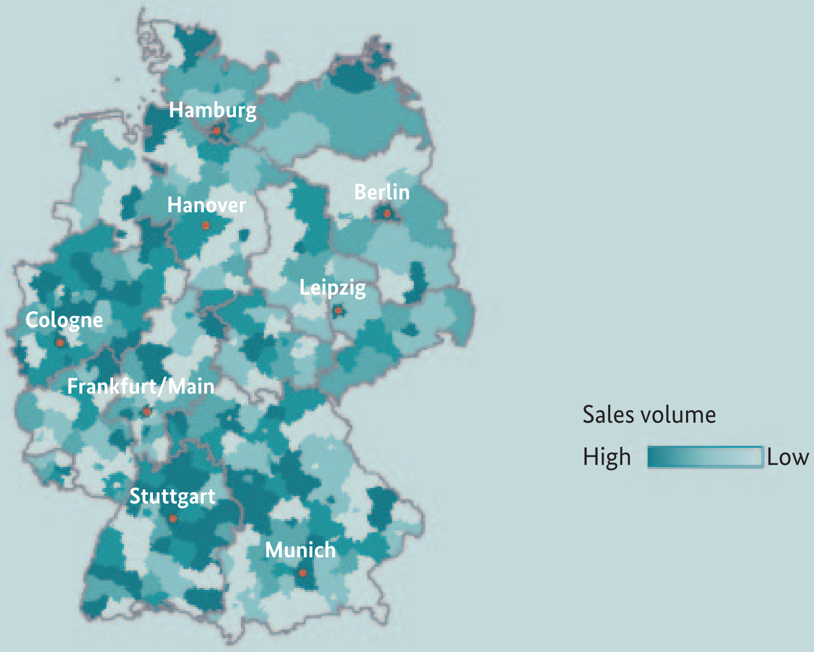
9 Territorial reforms have redefined the boundaries of administrative districts in some federal states.

Map 3: Regional distribution of service companies in the market for environmental technology and resource efficiency, by administrative district



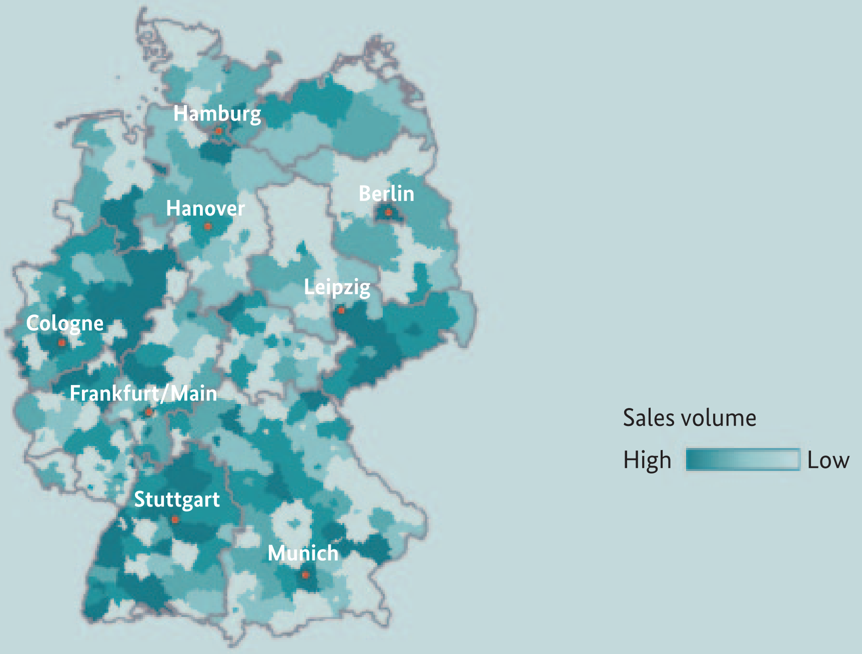
Source: Company survey (2,432 responses), Roland Berger (2017)

Map 4: Regional distribution of sales volume in the lead market for environmentally friendly power generation, storage and distribution, by administrative district



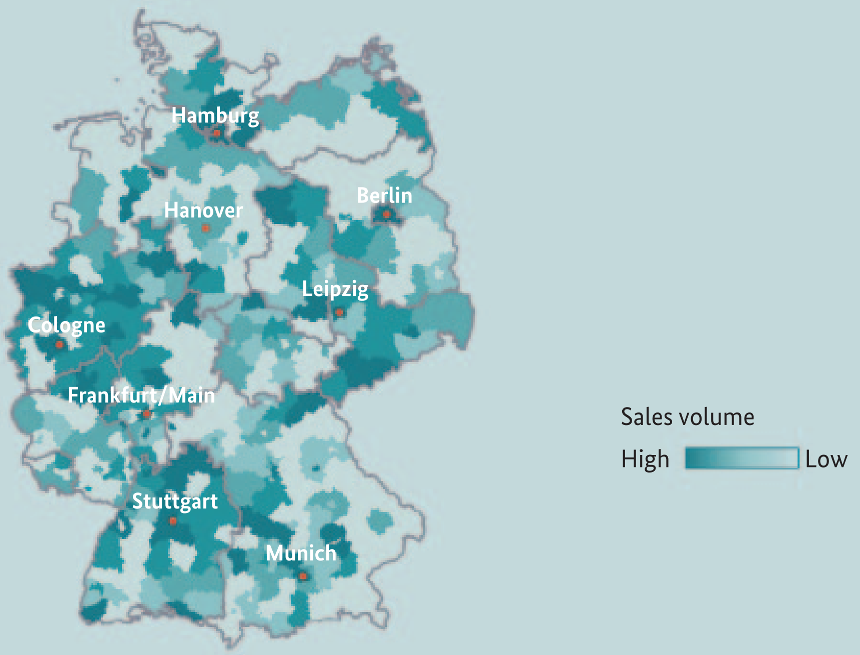
Source: Company survey (884 responses), Roland Berger (2017)

Map 5: Regional distribution of sales volume in the lead market for energy efficiency, by administrative district



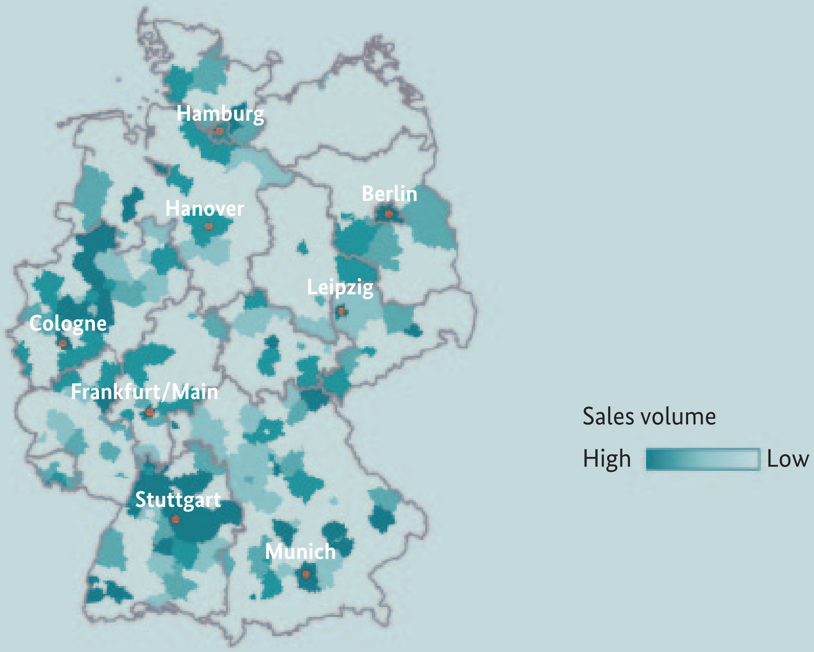
Source: Company survey (840 responses), Roland Berger (2017)

Map 6: Regional distribution of sales volume in the lead market for material efficiency, by administrative district



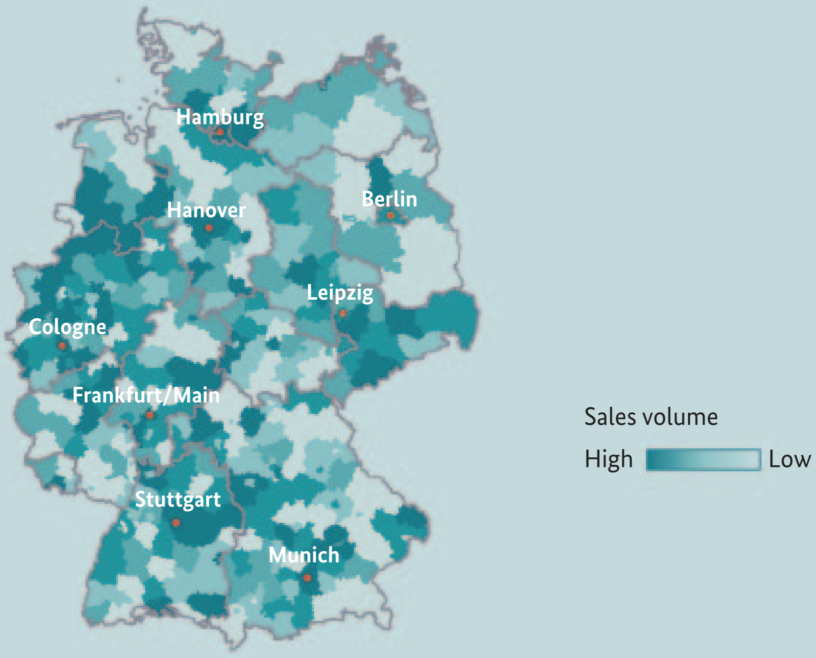
Source: Company survey (484 responses), Roland Berger (2017)

Map 7: Regional distribution of sales volume in the lead market for sustainable mobility, by administrative district



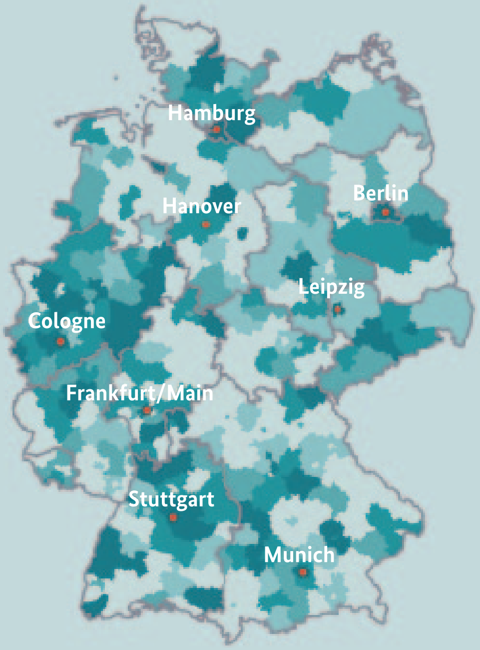
Source: Company survey (90 responses), Roland Berger (2017)

Map 8: Regional distribution of sales volume in the lead market for waste management and recycling, by administrative district



Source: Company survey (771 responses), Roland Berger (2017)

Map 9: Regional distribution of sales volume in the lead market for sustainable water management, by administrative district



Sales volume

High Low

Source: Company survey (521 responses), Roland Berger (2017)

Green tech "made in Germany" on foreign markets

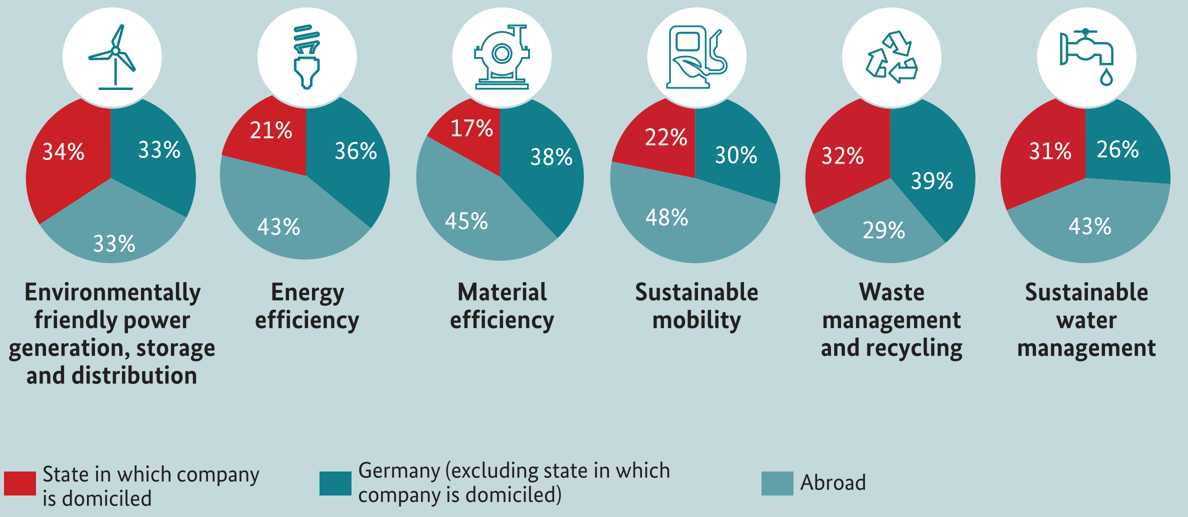
Environmental technology and resource efficiency products, processes and services that bear the label "made in Germany" are much in demand on international markets. Building on the foundation of a robust domestic market, German green tech providers have positioned themselves well outside their home country. Figure 58 shows these companies' regional sales distribution, broken down by lead market focus. Across the individual lead markets, the export rate[10] ranges from 29 to 48 percent. To put these figures in perspective: The export rate for the German economy as a whole was 38.5 percent in 2016.[11]

The share of sales realized abroad is highest in the lead markets for sustainable mobility (48 percent) and material efficiency (45 percent) – a clear indication that companies focused on these lead markets have a pronounced export orientation.

Sales generated in Germany can be broken down into activities in a company's home state (i.e. the federal state in which they are officially domiciled) and activities in other German states. This distinction shows that many German green tech providers still maintain a strong regional orientation.

Companies focused on the lead market for environmentally friendly power generation, storage and distribution generate 34 percent of their sales in the federal state in which they are domiciled – slightly more than the comparable figure for the other lead markets. This fact can be seen as indicative of the growing importance of distributed power supplies. Companies focused on waste management and recycling generate 32 percent of their sales in their home state – a clear reflection of the exceptionally high levels of regional value added and customer loyalty that prevail in this lead market.

Figure 58: Distribution of sales by region and lead market focus (percent)



Source: Company survey (2,267 responses), Roland Berger (2017)

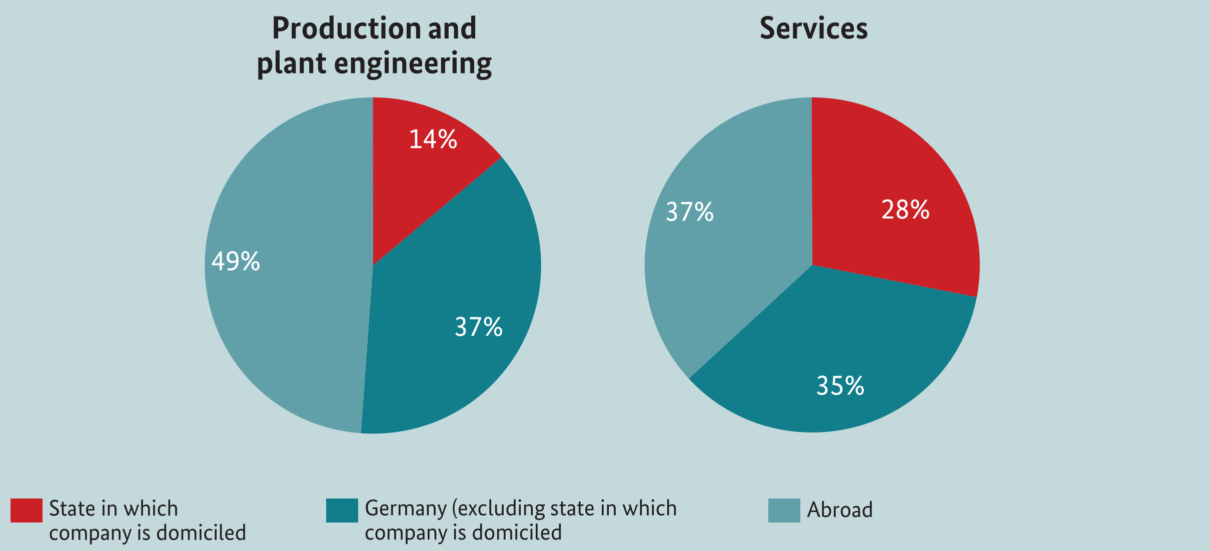
10 The export rate is the percentage of sales generated outside Germany.
11 See Statistisches Bundesamt (2017c).

Figure 59 visualizes the regional distribution of sales posted by service companies on the one hand and companies focused on production and plant engineering on the other. Green tech firms that sell only services generate 37 percent of their sales outside Germany. The export rate for companies in the production and plant engineering segment is 49 percent. The other side of this coin is that service providers evidence a much stronger regional orientation, generating 28 percent of their sales in their home state. That figure is twice as high as the corresponding figure for production and plant engineering firms.

Which international target markets do German green tech providers see as the most important today? And which ones will be the most important in the future? The answers to these questions provide valuable input to forecast the trajectory of the ongoing process of internationalization in Germany's environmental technology and resource efficiency sector. The responses derived from our analysis of company data are visualized in Figures 60 and 61.

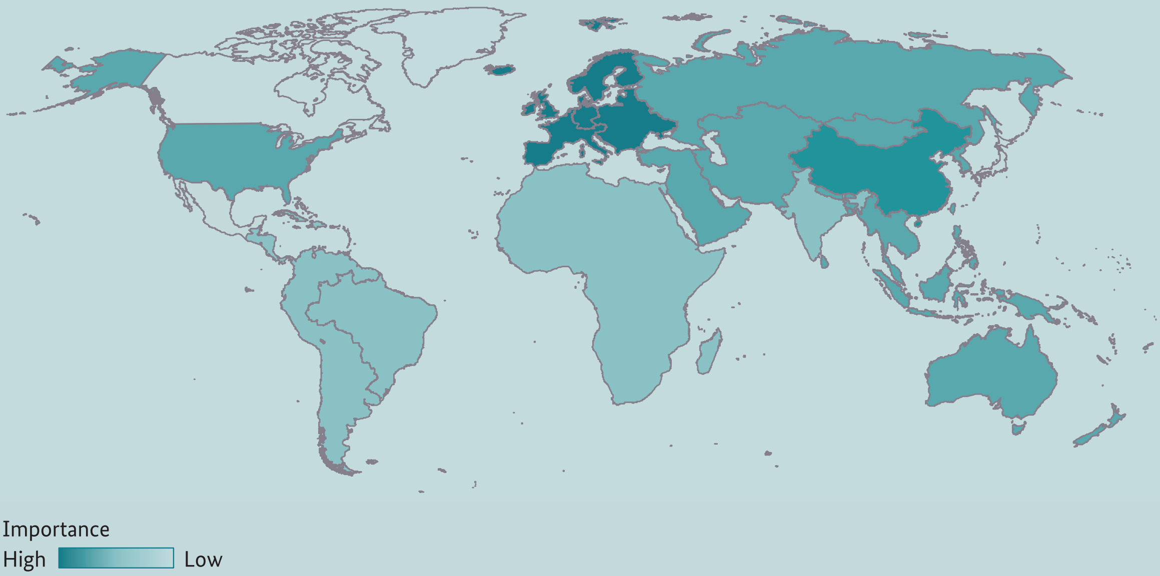
The companies surveyed still regard Europe and China as the most important international target markets for environmental technology and resource efficiency. Between now and 2025, they expect Russia to become a more significant target market. Brazil, India, China, the Middle East, Africa and North America will also play an increasingly important role as export destinations for green tech made in Germany.

Figure 59: Distribution of manufacturing companies' and service providers' sales by region (percent)



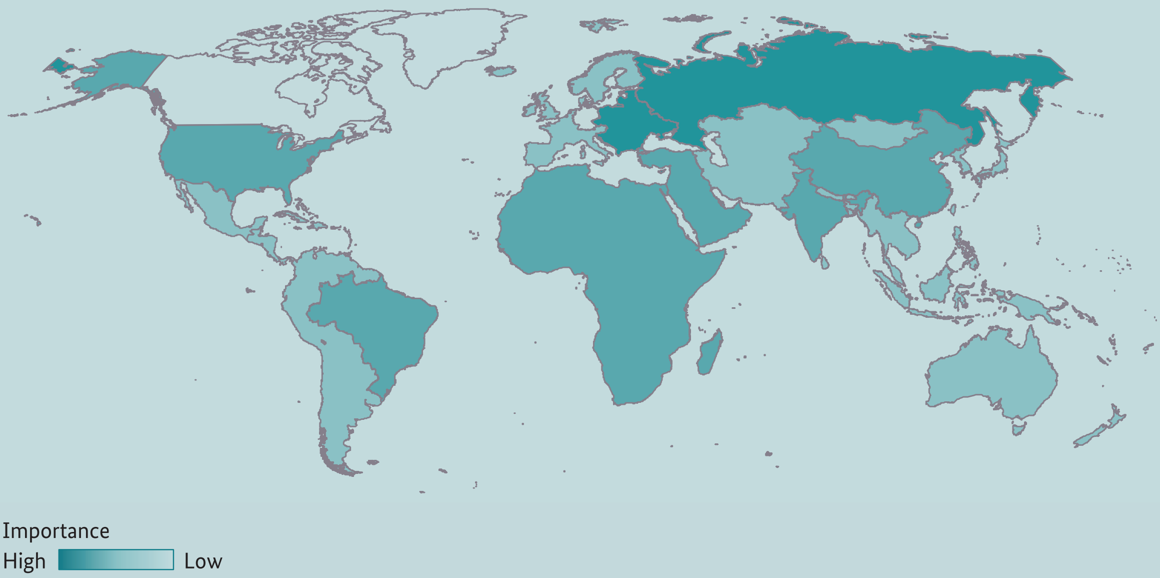
Source: Company survey (2,212 responses), Roland Berger (2017)

Figure 60: Importance of international sales markets in 2016 from the perspective of respondent companies



Source: Company survey (2,560 responses), Roland Berger (2017)

Figure 61: Expected increase in the importance of international sales markets through 2025 from the perspective of respondent companies



Source: Company survey (2,560 responses), Roland Berger (2017)

Figure 62 lists the five technology lines that are believed to present the strongest export opportunities in individual countries. Figure 63 does the same for entire regions.

Figure 62: Top five technology lines by country, attractiveness and lead market

Brazil

1	Composite materials
2	Energy-efficient lighting
3	Processes in the chemical industry
4	Energy efficiency in the manufacture of mineral products
5	Biotechnology

China

1	Electronic storage of energy
2	Hybrid drive systems
3	Electricity generation and distribution equipment
4	Efficiency gains in combustion engines
5	Measurement and control instrumentation

Canada

1	Biotechnology
2	Energy-efficient lighting
3	Hydrogen from renewable resources
4	Bioethanol
5	Electric drive systems

Mexiko

1	Composite materials
2	Energy efficiency in food production
3	Efficiency gains in combustion engines
4	Energy efficiency in paper and cardboard manufacturing
5	Energy-efficient lighting

Source: Company survey (2,560 responses), Roland Berger (2017)

Figure 63: Top five technology lines by region, attractiveness and lead market

India

1	Efficiency gains in combustion engines
2	Composite materials
3	Renewable resources as feedstock for the chemical industry
4	Energy efficiency in the cement industry
5	Electricity generation and distribution equipment

Japan

1	Bioplastics
2	Energy-efficient lighting
3	Water efficiency technologies in agriculture
4	Efficiency gains in combustion engines
5	Energy efficiency in food production

Russia

1	Water efficiency technologies in agriculture
2	Innovative sanitation systems
3	Composite materials
4	Energy efficiency in the cement industry
5	Water efficiency technologies in households

USA

1	Composite materials
2	Nanotechnology
3	Bioethanol
4	Innovative sanitation systems
5	Energy efficiency in food production

Source: Company survey (2,560 responses), Roland Berger (2017)

Spotlight: Industry expertise and a profile as a system solution provider strengthens companies' position on foreign markets

All over the world, environmental technology and resource efficiency products, processes and services will be increasingly in demand in the coming years (see Chapter 4). The expansion of green tech markets will largely be shaped by international climate policy: If the targets set by the Paris Agreement are to be met, the signatory states must resolve and implement ambitious plans to reduce greenhouse gases at the national level. German players have a good chance of benefiting from growing global demand on the markets for environmental technology and resource efficiency. Emissions of greenhouse gases can be curbed only if energy efficiency is improved and further progress is made in decarbonizing the energy industry by ramping up the use of renewable energy. Both advances must be made worldwide. And in both areas, green tech providers in Germany possess the necessary experience, knowledge and comprehensive portfolios.

Cutting energy consumption in industry and commerce is crucial if energy efficiency is to be improved. In particular, emerging nations that are currently in industrialization phase have huge demand for energy-efficient plant and machinery. In industrialized countries, production facilities are being upgraded to meet more exacting requirements for energy efficiency. This demand profile perfectly matches the strengths of the German economy in the export arena. Products made in Germany are generally held in high regard on the international markets. In industries such as automotive, electrical, mechanical and plant engineering and the chemical sector, Germany enjoys a global leading position. Industry accounts for 22.5 percent of the gross value added in Germany and has an export rate of 50 percent.[12]

Backed by such a strong industrial base, mechanical and plant engineering has evolved into a "technology driver" in Germany.[13] Germany proudly bears the title "export world champion in mechanical engineering", and German companies command the largest share of global exports in 18 out of 31 branches of the mechanical engineering industry.

In large-scale plant engineering, German firms lead the line internationally: 87 percent of their production (of power, electric, chemical, building material and smelting plants) is exported: "German plant engineers are the first port of call even when whole countries target (re)industrialization. Quality, reliability, service, efficiency and environmentally friendly solutions are key assets possessed by the Germans."[14]

Given this enviable position, German providers are ideally placed to supply international markets with the technologies they need to master the major challenges facing industry: energy efficiency, environmental protection and digitalization. Process automation has a large part to play, and this is another field of technology in which German companies occupy a very strong position: "Germany predominates in automation technology, is revolutionizing robotics and is out in front in digital production. It is also leading the way in the future market for virtual systems and rolling out a constant stream of new solutions for production systems that are both highly complex and efficient. Furthermore, Germany also supplies the software for high-precision production control."[15]

In light of the need to decarbonize, many countries face the challenge of designing low-carbon power supply systems. The experience Germany is gathering from its own energy transition could prove valuable: "If the project is a success, it could become a blueprint or template for other countries."[16] Technological advances in generating power from renewable sources, the ability to integrate these volatile renewable energy sources in the grid and the dovetailing of power, heat and mobility solutions are giving German providers an advantage in terms of knowledge and experience on the international markets.

Generally speaking, emerging nations hold out attractive prospects for German providers of products, processes and services in the lead market for environmentally friendly power generation, storage and distribution and the lead market for energy efficiency. Emerging countries in particular have the chance to "leapfrog" certain steps in the development process. In the context of power supply, that can involve a country building distributed (sub)systems from the outset, without first establishing a conventional, centralized power grid. In the context of industrialization, leapfrogging can mean

12 See Bundesministerium für Wirtschaft und Energie (2017f).
13 See Deutsche Bank Research (2016), page 8.
14 Ibid., page 8.
15 Ibid.
16 Ibid., page 9.

planning greenfield plant with a view to energy-efficient and material-efficient process automation right from the word go.

German companies are widely attested to be extremely competent in system solutions.[17] On international green tech markets, too, this strength will prove to be a key success factor, as innovations in environmental technology and resource efficiency are increasingly being driven by systemic developments and less by isolated innovations. As a rule, system solutions are better suited to mastering the complex challenges of mitigating climate change and protecting the environment. Individual components are linked together to form systems and create end-to-end solutions. Physical and technical losses impose limits on the efficiency of individual solar cells, for example. Stand-alone photovoltaic installations experience a time lag between the generation of power and the demand for that power. Low output likewise causes difficulty regarding integration in the power grid. Each of these components thus has shortcomings that can be minimized only at the cost of substantial research and investment outlays. However, if we shift our focus to the entire power generation, storage and use system, far greater potential for improvement arises than if each component is regarded in isolation.

Digitalization is seen as an enabler of systemic solutions. It is therefore reasonable to expect that digitalization will unleash huge momentum to drive the formation of systems in environmental technology and resource efficiency.

17 See acatech – Deutsche Akademie der Technikwissenschaften e.V. (2013), page 5.

6 Fresh potential: Digitalization in environmental technology and resource efficiency

Digital transformation – The opportunities and risks

The megatrend we know as digitalization has long since taken hold of the green tech industry. New players and new business models are challenging incumbent firms, who must now defend their position on markets where the digital transformation will bring major changes in the coming years.

At a glance

Digitalization will further accelerate the pace of growth in the green tech industry. In 2025, environmental technology and resource efficiency can expect it to add an extra 20 billion euros to the market volume. Digital data, automation, digital interfaces to the customer and connectivity are driving greater investment in green products, processes and services that are instrumental in avoiding or reducing pollution of the environment. In Germany alone, the digital transformation of environmental technology will save about 50 million tonnes of CO_2 equivalent in 2025.

Five digital systems in particular are hugely important to the green tech industry and harbor considerable environmental relief potential. They are: connected energy, building information networks, Industry 4.0, urban connected mobility and smart grids. However, if environmental technology and resource efficiency companies are to benefit from the digital transformation, they must adapt to the new rules of the game brought about by the transition to the digital age. These rules state that new, disruptive business models are replacing old business models; that traditional corporate structures are becoming more flexible; that virtual platforms are forcing changes in market design; that new competitors are penetrating links in the value chain; and that network effects are becoming established as a new competitive advantage.

The digital transformation at a glance

“Megatrends are enormous shifts that genuinely change our society.” That is how John Naisbitt, the intellectual father of the megatrend concept, explains what distinguishes hyped-up buzzwords from megatrends.[1] Phenomena such as climate change, globalization, demographic change, urbanization and digitalization belong in this category. These developments have a mutual impact on each other and will shape not only the world we live in today, but also the social, political and economic conditions that prevail in future generations. Logically, therefore, megatrends also have a significant influence on the corporate environment. Digitalization is seen as both a megatrend and a driver of innovation. It affects all areas of social and economic life. At every link in the value chain, companies are encountering connected systems and working with tools and practices that are based on information and communication technology. In the process, the part played by the latter is changing. Digital technology no longer merely supplies auxiliary tools: It is bringing fundamental change to companies’ business models and processes. The level of intensity may differ, but the digital transformation affects every industry and every business enterprise, from large corporates to SMEs.

The far-reaching impact digitalization can have is graphically illustrated by pioneering industries such as the media (the eroding importance of print media), the music industry (fully digitalized products and sales channels) and retail (online shopping).

Literature on the subject currently provides no solid definitions of what exactly the “digital transformation” entails.[2] The discussion that follows is rooted in the following understanding: “We understand digital transformation as end-to-end connectivity across all areas of the economy, and as the [relevant] actors’ adjustment to the new conditions that prevail in the digital economy. Decisions in connected systems involve data exchange and analysis, the computation and evaluation of options, and the initiation of actions and the resultant consequences. These new tools will change many established business models and value creation processes from the ground up.“[3]

1 See Naisbitt, John (2015), page 5.
2 See Schalmo, Daniel/Rusnjak, Andreas (2017), page 3.
3 See Roland Berger Strategy Consultants GmbH/Bundesverband der deutschen Industrie e. V. (eds.) (2015), page 6.

Digitalization will also bring change to environmental technology and resource efficiency. This chapter discusses the opportunities and risks with which digital transformation confronts players in the green tech industry.

The four keys to digital transformation

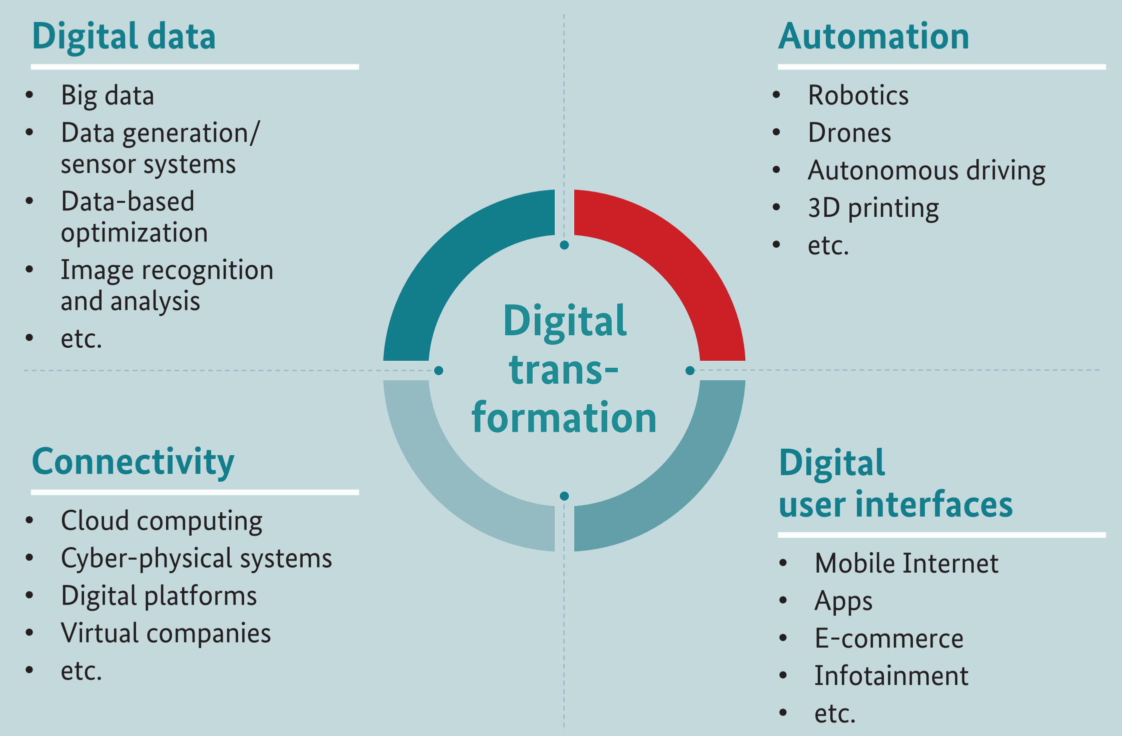
As digital data becomes available, production processes are automated and digital interfaces to the customer are crafted and joined up, business models are being transformed and whole industries reshuffled. These four keys to digitalization are also influencing the structure of the market for environmental technology and resource efficiency (see Figure 64).

Digital data
The volume of data generated worldwide doubles every two years and is expected to reach 40 zettabytes by 2020. To put that in perspective: a zettabyte has 21 zeroes after the 1. Yet the issue is not only the multiplication or sheer volume of data, but also the qualitative aspects of speed and diversity. Never before was it possible to analyze such a large volume of varied data in a short space of time. Collecting, processing and analyzing digital measurement data allows forecasts to be made and recommendations to be issued. In the green tech industry, for example, a constant stream of new applications is emerging for the use of sensors and digital data. There is no shortage of examples: Cassantec AG uses big data derived from sensors to analyze processes on wind farms. A series of mathematical methods are applied to this data to identify risk profiles, status trends and the residual service lives of wind turbines. The planning of maintenance and servicing can be improved as a result (moving in the direction of "predictive maintenance").

Digital data analytics is also used in the water industry. Kisters AG helps water utilities to optimize their operations and thus play their part in the efficient management of water resources. For example, data analytics enables pump station operations to be scheduled with a clearer focus, storage capacity to be planned to a more granular level and energy usage to be monitored.

Automation
Electronics and information technologies have been deployed to automate production processes since the 1970s, so automation cannot be described as a new trend. That said, the digital transformation has taken it into a new dimension. Combining machinery with cutting-edge information and communication technology is giving rise to dynamic, self-organizing, enterprise-wide value networks that are optimized in real time. In the process, cyber-physical systems

Figure 64: The four keys to digital transformation, with sample applications



Source: Roland Berger (2017)

(CPSs) are assuming a key role: A CPS is made up of a processor that can communicate with other CPSs over the Internet, sensors to perceive its environment and actors to influence that environment. Cyber-physical systems lay the technological foundation on which IT can combine with the physical world. They therefore play an essential part in smart factories in the vein of what has been called Industry 4.0.

The integrated energy management technologies developed by Siemens AG's Digital Factory Division provide are an example of the new potential for automation to improve energy efficiency. Programmable controllers enable plant and machinery to communicate their level of energy efficiency. The control unit then acts accordingly, orchestrating the production plant on the basis of the information it has received.

Digital customer interface

Websites, software, apps and social networks give companies digital interfaces to their customer. They open up new opportunities to market more individualized products and services and intensify their interaction with market players. Providers such as GreenPocket GmbH are putting these benefits to good use: The Cologne-based company develops software solutions for smart metering and the smart home that help both private households and commercial users to significantly improve their energy efficiency. Users of GreenPocket's software see their energy consumption data visualized intuitively on a variety of devices such as tablets, smartphones and PCs.

Connectivity

In the context of digitalization, connectivity relates to the data exchange infrastructure. That can serve communication between machines (machine-to-machine, or M2M), in which the same data types are normally shared. But it can also serve the exchange of data in different formats for a variety of applications and users – via the cloud, for instance. One example of connectivity in the lead market for sustainable mobility is Moovel. The Moovel app brings together the offerings of car-sharing provider Car2go, the Mytaxi start-up, German railway operator Deutsche Bahn and the local public transport systems in many regions. This joined-up approach creates a dedicated digital ecosystem in the field of mobility.

These examples suffice to show that all four keys to digital transformation are being applied to digital green technologies and business models. And it is this interplay in particular that gives digitalization its dynamism and innovative strength.

Digital systems changing the market

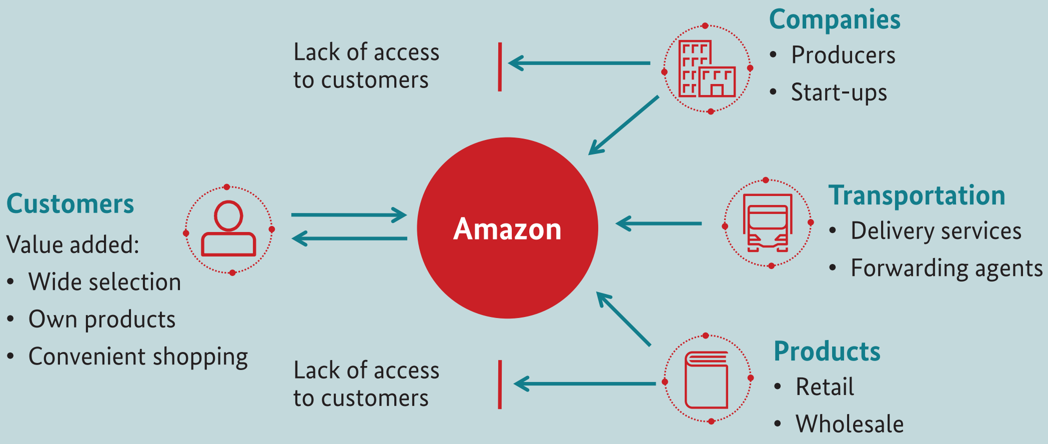
Digitalization and its four keys are increasingly serving as enablers for the formation of systems.
Digital systems use a self-organizing digital infrastructure to create an environment within which connected organizations and devices can both collaborate and share knowledge and information. In this way, they support the development of open and adaptive technologies as well as evolutionary and disruptive business models.

However, pure-play digital enterprises such as Alphabet (Google), Apple, Microsoft and Amazon are seeking to close their digital systems in order to give themselves competitive advantages. Yet doing so prevents any "cross-pollination" between technologies and components. Environmental technology and resource efficiency companies can learn and benefit from these digital-only players, who highlight the opportunities afforded by the development of digital business models: The technology giants develop new kinds of business models, set up innovative corporate structures, try out new strategies, radically exploit the possibilities opened up by digitalization – and make an impressive case for what developing digital business models can achieve. In analyses of the likes of Alphabet, Amazon and Facebook and their secrets of success, three words crop up again and again: disruption, platform and network effects. Taking Amazon and Alphabet as examples, let us briefly outline what these terms mean.

Two factors in particular set Amazon apart from the crowd. The company is rigorously self-disruptive, and it leverages its immense market power as the dominant platform provider in online retail. In its capacity as a central platform, Amazon has amassed market power that creates both pull and push effects. On the one hand, small companies, start-ups, publishing houses and private individuals are pulled (via the Amazon Marketplace) toward the platform, as it gives them excellent opportunities to reach customers around the globe quickly and easily. On the other hand, customers themselves become sellers on the marketplace, as well as disclosing digital data through their shopping habits and the ratings they give. Amazon uses this data to select and enlarge its portfolio and to improve the service it providers, making the platform ever more attractive for customers and businesses alike.

Successful platform formation allows Amazon to occupy the interface to customers, thereby effectively blocking other companies' access to customers. In this way, Amazon erects a virtual barrier that prevents

Figure 65: Amazon – A central platform with pull and push effects



Source: Roland Berger (2017)

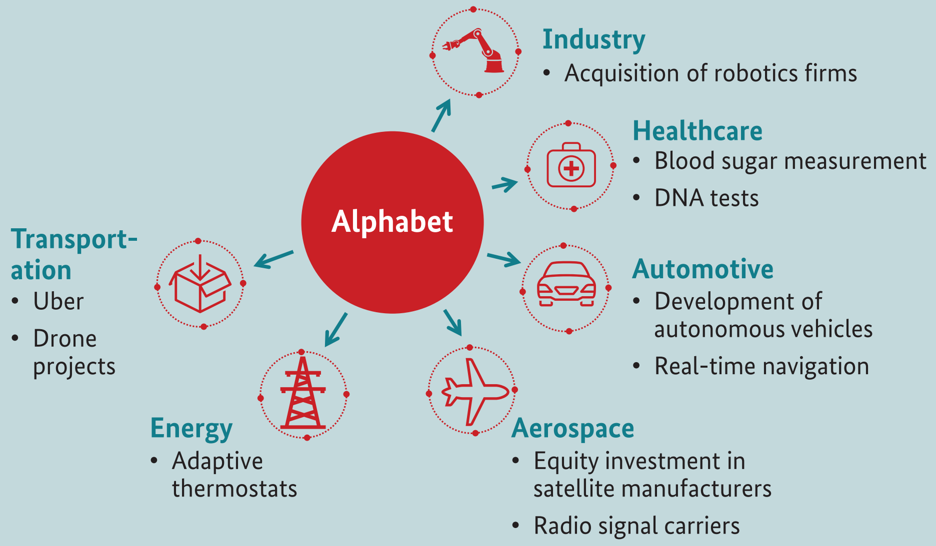
established players from interacting directly with customers (see Figure 65). This in turn creates a push effect for intermediaries and delivery services.

The huge success of its search engine is by no means Alphabet's only trump card. In its capacity as a digital system, it is fascinating above all because it clearly has the resolve to drive the digital transformation in completely alien markets and industries. Many customers know Alphabet as the Google search engine and a provider of online services. The company itself, however, is both astute and systematic in the way it harnesses its advantages and digital experience – in the use of data and optimization algorithms, for example – in an attempt to transfer this knowledge to other industries (see Figure 66).

Alphabet has thus acquired manufacturing companies in the home automation segment and is currently invested in the production of cars, drones and satellites. Underpinning many of its commitments is a desire to transform existing business models by combining knowledge with technological expertise. Yet the company's evolution does not follow strategic plans alone. Products and offerings have been tested based on the principle of trial and error. Services that turned out to be neither successful nor profitable – such as Google Buzz, Google Labs and Google Desktops – were discontinued in short order.

Unlike pure digital players such as Google, many of today's companies were founded in the analogue era and now face the challenge of actively shaping the digital transformation within their organizations. Their hand is being forced, because digitalization is changing the rules of the game in their markets. And as a result, digital systems are creating more or less pressure – depending on the industry – to align business models with the new digital conditions. This transformation of legacy business models can be illustrated by the example of the Port of Hamburg.

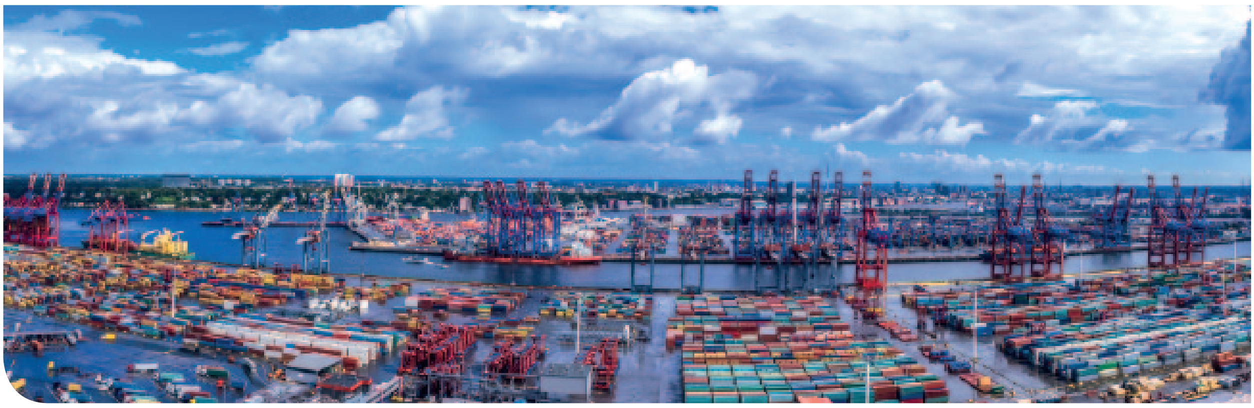
Figure 66: Google's industrial projects and equity investments (excerpt)



Source: Roland Berger (2017)

Example: Port of Hamburg
MThe Port of Hamburg occupies 7,200 hectares of space close to Hamburg city center, i.e. a considerable distance from the coast. This geographical handicap limits its room for expansion: Around 8.9 million standard containers (TEUs) were transshipped via the Port of Hamburg in 2016, but one assessment of potential suggests that this figure could rise to 25 million standard containers by 2025.[4] Since this growth target cannot be realized solely by enlarging the port's footprint, the operator, Hamburg Port Authority (HPA), is turning to other options to facilitate continued expansion. The aim is to improve port's efficiency as an important link in the supply chain by deploying smart solutions ("smartPORT logistics") for the flow of traffic and goods. "We can optimize the use of traffic routes and, for example, optimize the speed at which container vessels pass through the port," explains Sebastian Saxe, Chief Digital Officer.[5] The smartPORT logistics concept focuses on the aspects of infrastructure, traffic flows and the flow of goods.[6]

Launched in 2013, the smartPORT logistics project essentially centers around connecting and analyzing a variety of data in the cloud. Some 800 sensors around the port take 100 readings per second: water levels, vessel positions, truck weights, and so on. As a result, the control center always knows exactly what is on board a given vessel and what route it plans to take. About 40,000 trucks pass through the port area every day, and

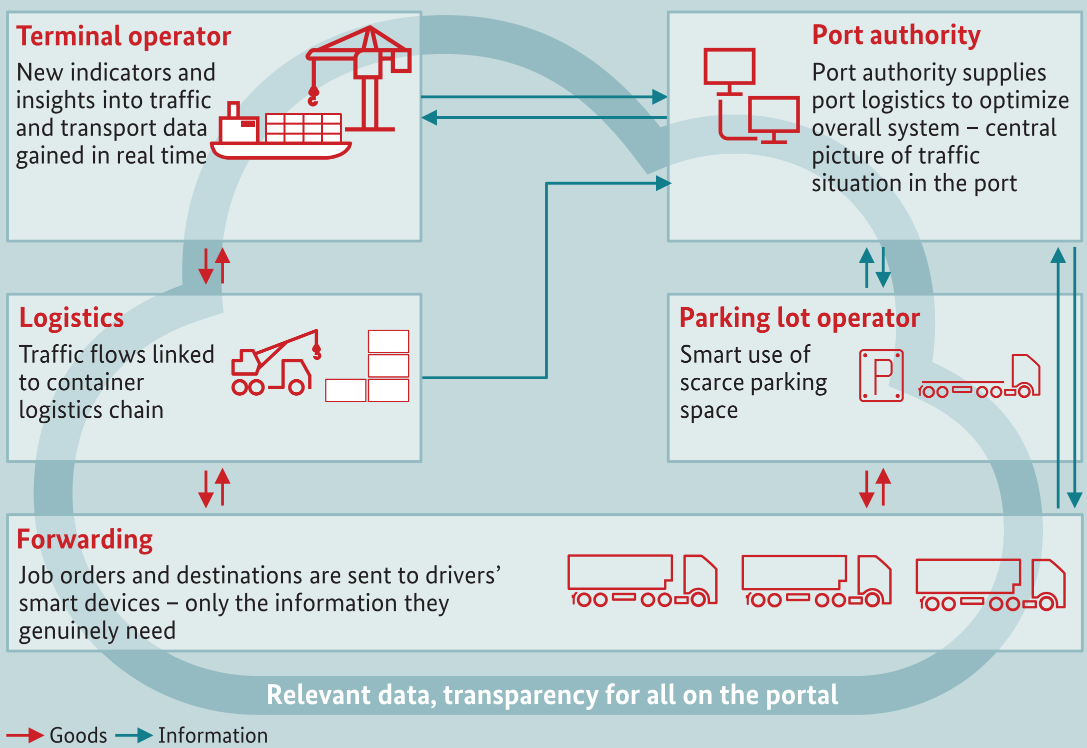


4 See Hamburg Port Authority (2017a).
5 See Google Deutschland (eds.) (2017), page 7.
6 See Hamburg Port Authority (2017b).

they all have to be coordinated. The cloud-based smartPORT logistics solution developed in cooperation with T Systems and SAP is deployed to master this challenge. Connected via a control center, each vehicle has its own mobile device and receives traffic management information. Fast information provisioning is imperative: Only by selecting and prioritizing information generated from the flood of data is it possible to genuinely help drivers and carriers in their work. The vehicle status, current wait times in loading/unloading zones and order data all come together in this information system.

The long-term aim is to connect traffic information for all means of transportation – shipping, rail and road traffic – via an intermodal port traffic center. This will provide all relevant information about the traffic situation in Hamburg's port area to all transport users and logistical decision makers in real time. Digitalization should thus simplify and optimize the control of traffic and goods flows. The resultant efficiency gains add economic value for the Port of Hamburg, but are also having a positive impact on the environment: Improved logistical processes are reducing air pollution and greenhouse gas emissions caused by vehicular traffic.

Figure 67: The Port of Hamburg's digital system



Source: Roland Berger (2017)

Five hypotheses about the digital transformation

The digital transformation – expedited by the four keys of digital data, automation, connectivity and digital customer interfaces – is bringing fundamental change to market structures and laying the basis for innovative systems. If environmental technology and resource efficiency companies are to be able to benefit from this development, they must adapt to the new rules of the game brought about by the transition to the digital age. The principal changes are subsumed here under five hypotheses:

- Hypothesis 1: New, disruptive business models are replacing old business models
- Hypothesis 2: Traditional corporate structures are becoming more flexible
- Hypothesis 3: Virtual platforms are forcing changes in market design
- Hypothesis 4: New competitors are penetrating links in the value chain
- Hypothesis 5: Network effects are becoming established as a new competitive advantage

New, disruptive business models are replacing old business models

The dictionary tells us that the verb "disrupt" means "to break apart", "to throw into disorder", "to interrupt the normal course of". These definitions say a lot about what disruptive technologies and business models do. The concept of "disruptive innovation" was first elaborated by Clayton M. Christensen, Professor at the Harvard Business School, in his 1995 book "The Innovator's Dilemma".[7] Disruptive innovation differs materially from incremental innovation. In some quarters, a similar meaning is given to juxtaposition of the terms "revolutionary innovation" and "evolutionary innovation". Innovations are described as disruptive when they fundamentally change the rules by which markets and/or individual industries operate. Closely linked to the notion of disruptive innovation is a phenomenon known as "digital Darwinism". "The term digital Darwinism aptly describes the process in which a lot of companies and industries currently find themselves – many of them without having been asked, and some of them without wanting to be there."[8] The formulation evokes a process of natural selection that takes effect when businesses or branches of industry are confronted by changed conditions. Depending on whether and to what extent they succeed in adapting, their market position will either improve or deteriorate.

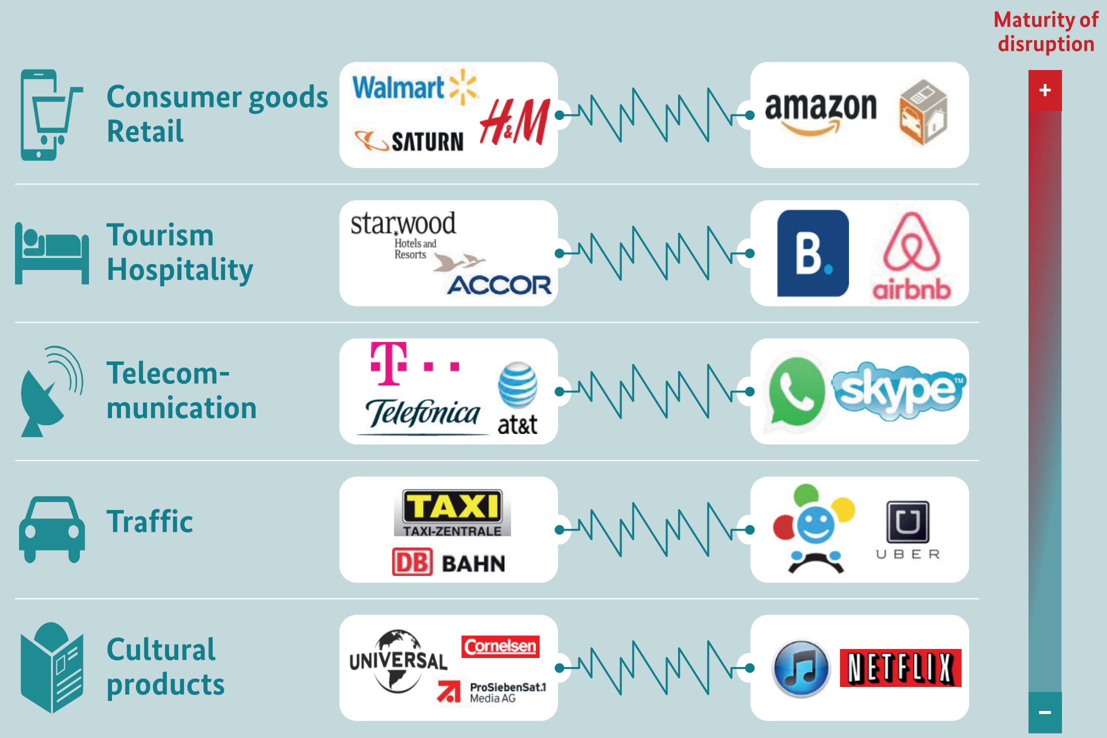
Disruptive innovations frequently begin in niche segments.[9] Taking new technologies and business models as the starting point, products and services are developed that initially appeal to only a small number of users. However, further development of these products, changes in customers' interests and preferences and injections of capital by investors then trigger disruptive development: The new offerings crowd out incumbent firms and their products and go on to dominate the market, which usually grows in size thanks to disruptive innovations. Such disruptive innovations only ever extend over a certain period of time.

The degree of maturity of disruption (see Figure 68) thus varies from market to market. Enterprises such as Netflix and iTunes, for example, are still in the early days of disrupting the market for cultural products. They sell music and film files and, in so doing, launch an assault on film studios' established business model, but also on that of TV channels and music labels. Meanwhile, in telecommunications, the use of messaging services such as WhatsApp is increasing relentlessly. The services themselves are likewise expanding their business model in the direction of online telephony. Conference calls can already be held over Facebook Messenger, for example.

Flash memory initially had too little memory space, was relatively expensive and was not particularly reliable, all of which left it clearly inferior to traditional hard drives. On the upside, flash memory cards were small, low on power consumption and thus well suited to use in mobile devices such as digital cameras and USB sticks. Over time, they found their way into more and more devices and applications. This in turn boosted the sale, production and development of flash memory, which consequently became better and ever cheaper. Today, flash memory cards are already substituting for conventional hard drives, in part because cloud solutions mean that users need less and less physical memory space on notebooks and tend to attach greater importance to memory speed.

7 See Christensen, Clayton M. (1997).
8 See Kreutzer, Ralph T. (2017), page 34.
9 See Fleig, Jürgen (2017).

Figure 68: Examples of disruptive business models with differing degrees of maturity



Source: Roland Berger (2017)

Traditional corporate structures are becoming more flexible

In many industries, digitalization is simplifying access to customers and thereby creating the conditions for a more pronounced customer orientation. This trend is confronting companies with new challenges, as they now have to foster a customer-oriented, digital mentality in place of the traditional product-oriented approach. That demands a willingness to accept cultural and structural changes.

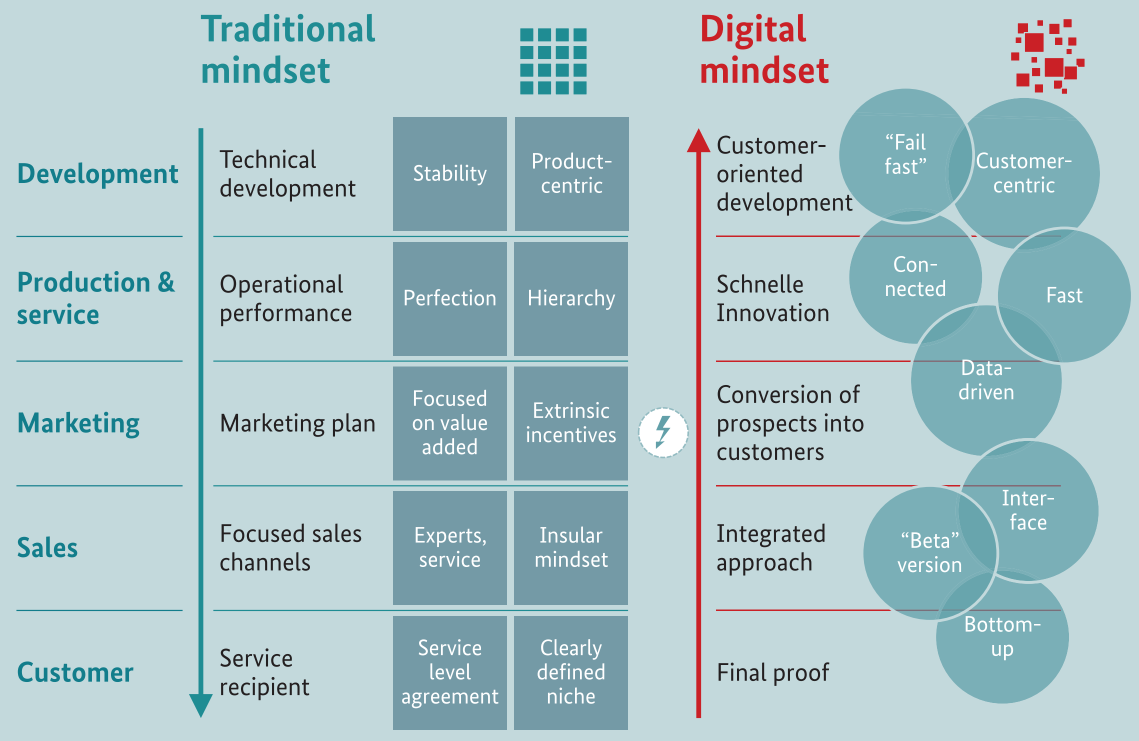
Figure 69 highlights the differences between the traditional and digital mentalities in corporate decision processes. In the past, such processes began with technical product development, from which every other link in the value chain (operational service delivery, marketing, sales etc.) followed. The digital mentality turns this approach on its head by taking customers and their (presumed) needs as its starting point.

To have something ready in good time with which to counter disruptive business models that threaten their own business models, and to be able to offer systemic solutions, more and more firms are forming alliances. If these intercompany teams are to succeed, all the companies involved required flexible structures and fast decision processes.

Virtual platforms are forcing changes in market design

Virtual platforms use the products and services of third-party players to seize sales opportunities. They occupy the interface to the customer and establish themselves as important sales platforms for other companies. This position then allows them to set the rules for selling and thus change the design of the market. The third-party companies themselves end up as mere suppliers, and lack of direct customer access leaves them unable to generate the data they would need to develop new business models. Not all platforms are online marketplaces: They can also be operating systems or comparison portals.

Figure 69: Principles and values – Comparison of companies with traditional and digital mentalities (based on companies' own statements)



Source: Roland Berger (2017)

Alphabet's Android operating system shows how a virtual platform can dictate the rules by which a market plays. App developers who want to sell their solutions on the platform must submit to the operator's rules. They must satisfy a large number of technical and content requirements prescribed for Android to even be accepted in the app stores. They also have to accept the high commission fees that Google charges on every sale.[10]

Nor are Apple, Google and Amazon the only virtual platform operators. Comparison platforms like Check24 are likewise fundamentally changing the market design in certain segments, such as in the electricity market.[11] Customers no longer contact power utilities to find out about electricity rates. Instead, they to turn to the Check24 platform to compare the terms offered by different providers. The portal then lets them book their chosen tariff directly. Traditional providers are thus losing interaction with customers and, hence, being deprived of direct contact with their target groups.

New competitors are occupying links in the value chain

Digitalization lets both start-ups and incumbents position themselves as new competitors in existing value chains. It helps companies get to know their customers better and develop new business models that line up with the latter's needs. In the process, businesses are discovering the need to expand their offerings into other industries, too. As a result, they can compete on new markets, disrupting – and in some cases replacing – incumbent players' value chains in their capacity as new competitors. In many cases, the value chains themselves thus become smaller. Moreover, to be able to continue to offer functionality, added value, products and/or services, companies become more closely interconnected.

In this process, traditional firms may lose the interface to their customers and the value chain, too, may change. These developments are starkly apparent in the banking sector, where diversified companies are now

10 See Ramge, Thomas (2015).
11 See Lünendonk GmbH (2015).

operating in what, for them, are completely alien lines of business that have nothing to do with their core business. Apple Pay and Google Wallet are bringing radical change to payment transactions by rendering cash, EC cards and credit cards surplus to requirements. Yet even telecommunication providers such as Deutsche Telekom are providing payment transaction solutions. And by granting loans to finance the purchase of their products, industrial conglomerates such as BMW and VW are delivering financial services that would traditionally have been handled by banks.

On the other hand, start-ups too are attacking what was hitherto the exclusive preserve of financial institutions. Rather than launch a major assault on the whole banking business, they focus instead on specific aspects of value creation. PayPal offers convenient ways to handle payment transactions in the digital realm. Kickstarter and Seedmatch are changing the face of corporate finance by raising capital via online platforms. Providers like Auxmoney broker private peer-to-peer loans in an attempt to challenge banks' traditional money lending role.[12] At best, traditional banks will thus find themselves demoted to the role of broker, losing both access to customers and parts of the value chain.[13]

Network effects are becoming established as a new competitive advantage

Network effects are rooted in the premise that every new customer adds greater benefits for all customers. Value-added services and new business models in the orbit around these networks can be harnessed to yield two competitive advantages: better products and an effective barrier to competitors.

Products can be continually improved thanks to the large number of users and their feedback, connectivity across devices and the gathering of data. It is also conceivable to use digital data to develop new services for customers. An example: Facebook tests whether new Messenger versions work, and the feedback from devices used by its customers show which functions are used frequently. These functions are then substantially improved to secure competitive advantages in product development.

At the same time, the barrier to entry for competitors is raised significantly. Compatibility problems between different network platforms are nothing unusual, meaning that, for customers, it is mostly more convenient to stay with their current network. Apple users, for instance, quickly become accustomed to the free iMessage function that only works between iPhones. This "lock-in effect" makes it more difficult for manufacturers of other smartphones to establish their products among groups of iPhone users.

12 See Roland Berger GmbH (eds.) (2016a).
13 See Roland Berger GmbH (eds.) (2016b).

Digitalization-driven development opportunities in environmental technology and resource efficiency

It is becoming harder and harder to improve individual environmental technology and resource efficiency services and products. The lead markets in this cross-sector industry have already reached an advanced stage of development, which makes it all the more important to pursue a systemic approach in the future. This kind of approach links individual components to form interlocking systems and thus create end-to-end solutions. By way of example, this section looks at five digital systems that are all of considerable relevance to the green tech industry. These examples clearly illustrate how digitalization creates positive stimulus for the ongoing development of environmental technology and resource efficiency by supporting and advancing systemic approaches.

More systemic approaches thanks to digitalization

Environmental technologies have already reached an advanced stage of development and can, in some cases, only be further improved by gargantuan efforts in terms of investment and research. The absolute efficiency of solar cells, for instance, is limited by physical and technical losses. In industrial production, monocrystalline silicon technology has remained in a constant efficiency range for years. In the case of stand-alone photovoltaic installations, there is usually also a time discrepancy between power generation and power demand, apart from the fact that low output makes integration in the grid problematic. That said, examining the overall system of power generation, storage and use definitely reveals untapped potential for improvement.

A similar picture is in evidence in the automotive industry. The potential to achieve efficiency gains in combustion engines through structural modifications is practically exhausted. However, merely rethinking motors and vehicles with alternative drivetrains (such as e-cars) would be a short-sighted approach: The environment, too, must be factored into all considerations. That includes both a charging infrastructure and innovative forms of customer access in order to deliver environmentally compatible mobility solutions.

These examples from solar power generation and e-mobility illustrate the complex challenges posed by climate and environmental protection – challenges that are difficult to master with isolated solutions. That is why demand is growing for systemic solutions. The cross-technology and interdisciplinary approach required for this purpose is inherent in the green tech industry's DNA (desoxyribonucleic acid): Connectivity and cooperation beyond the boundaries of individual disciplines are typical attributes of cross-sector industries such as environmental technology and resource efficiency.

Today, digitalization is increasingly evolving into a driver of systemic solutions. The four keys to digitalization (digital data, connectivity, automation and digital customer access) prepare the ground for innovative systems that can be used to meet environmental protection and climate action targets.

In this context, digitalization increases the volume of data, which is collected by more and more sensors in devices and equipment. The volume grows not least because data is gathered at ever shorter intervals and, ultimately, in real time. In joined-up systems, this data is then transferred to a control center.

One of the most important factors is connectivity between the individual system components. A high-performance (broadband) network is needed to make data exchange and ever higher transmission volumes possible in the first place. For the stationary transmission of large volumes of data, a broadband connection is an indispensable prerequisite. Yet mobile data transmission facilities are equally vital. The development step from LTE to 5G has brought us within touching distance of mobile transmission rates of 10,000 Mbit/s. In addition, technologies such as near-field communication (NFC), a new wireless data transfer standard, can now also be used to facilitate straightforward communication between the sensors in a device.

Building on faster, simpler and more accurate data exchange between devices, it becomes possible to develop self-organizing systems. These can increase both the accuracy and the speed of the work to be done, thereby helping to reduce operating costs. A crucial role is played by the combination of traditional technology and artificial intelligence. Automation is thus a critical driver of systemic approaches in environmental technology.

Digitalization and rebound effects

The efficient use of energy, materials and water is fundamental to the sustainable use of resources, with lower costs often delivered as a welcome side-effect. One less desirable consequence of greater efficiency is what is known as the rebound effect. This effect "describes the difference between the saving an efficiency measure is theoretically expected to yield and the saving that is actually realized."[14] The example of an LED lamp illustrates how a more energy-efficient device can influence people's purchasing behavior and patterns of usage: If a conventional light bulb is replaced by an LED lamp, power consumption will decrease given constant lighting power. However, if two LED lamps are installed in place of one conventional light bulb, the rebound effect (greater usage) ensues. More intensive use (fitting an LED lamp with greater luminance) and more frequent use (leaving the lamp on for longer) are other variations on the rebound effect theme.

A distinction is drawn between direct and indirect rebound effects. In the case of the direct rebound effect, "the more efficient good or service [...] is used more, more frequently or more intensively after the efficiency gain, thereby directly offsetting part of the energy saving", according to the definition used by the Federal Environment Agency.[15]

Direct rebound effects are conceivable if the use of energy-efficient environmental technology and resource efficiency solutions is not adjusted in line with demand. If a production plant is not switched on when a digitally connected system recommends that this should be done, for example, the potential efficiency gains will obviously not be realized. Even the wider use of car-sharing instead of (more energy-efficient) public transportation can lead to direct rebound effects. In the same way, the rising demand for energy prompted by the increased use of electronic devices within the framework of digitalization can also be classed as a direct rebound effect. On the one hand, digital offerings are needed to create the conditions for energy-efficient solutions. But on the other hand, they themselves also contribute to higher resource consumption (see the box on "Obsolescence").

Digitalization can likewise trigger indirect rebound effects on both the microeconomic and macroeconomic levels. Because of what they save on energy consumption, the users of energy-efficient building solutions, for example, have more money to spend on other things – such as long-distance air travel that entails a sizable CO_2 footprint. Similarly, efficiency gains in energy and material consumption give companies the chance to invest more in tangible assets or to expand production. That in turn can lead to higher energy input if it does not replace other types of products or the products of other vendors. On the macroeconomic level, efficiency gains can improve overall productivity and thus contribute to more forceful economic growth, which in turn can boost macroeconomic energy input. Along the same lines, lower energy consumption caused by energy efficiency can also result in lower market prices for energy, which can then drive stronger demand for more attractively priced energy among other market players.[16] It is even possible for rebound effects to cancel out and exceed the reduction in consumption (a scenario referred to as "backfiring").

Empirical estimates of rebound effects depend on the methods used and the effects included. It would seem especially difficult to draw a clear line between growth effects and the effects of structural transition. It follows that the different studies produce a very broad spectrum of effect estimates. The most important factors of influence are the nature of the products and services used, the saturation of the market with goods and the level of income. For instance, observations show that direct rebound effects are comparatively lower in high-income countries than in developing countries, where extra income is often immediately spent on greater consumption in order to raise the quality of life. Estimates of rebound effects relating to room heating vary between 10 and 30 percent of the posited savings potential. In traffic contexts, studies point to rebound effects of around 20 percent. The concrete extent of a given rebound effect is nevertheless heavily dependent on the specific conditions and can be reduced by a variety of instruments.

14 See Umweltbundesamt (2016f), page 4.
15 Ibid.
16 See Umweltbundesamt (2014).

Digitalization creates new approaches that work well to combat rebound effects: dematerialization, information and automation. The dematerialization of many products and processes in the course of digitalization can naturally lead to rebound effects of its own. However, these effects occur in the digital, dematerialized world.[17] The music industry is a good example: Digitalization has actually increased the number and variety of music tracks sold, but physical recording media such as CDs have become virtually obsolete.

Digital data and digital customer access also create the opportunity to gain a far better understanding of rebound effects than in the past, and hence to formulate effective solution strategies and behaviors that genuinely save resources. Digitalization enables the playful style of app functionality, integration in social networks and the visualization of data to be harnessed in a way that creates powerful incentives to attenuate rebound effects.

At the same time, automation in the systemic solutions used in digital environmental technology are increasingly simplifying the task of efficient management and control. Many systems are themselves able to process digital data and can therefore optimize themselves and/or the processes within which they operate. Such pre-programmed optimization means that direct rebound effects can be virtually ruled out.

To summarize: Rebound effects must always be borne in mind as possible obstacles to the realization of potential savings. Nevertheless, neither these effects nor potential efficiency gains can ever be considered in isolation: Both must always be seen in their wider context. Digitalization harbors promising potential to prevent or at least significantly reduce rebound effects. This potential derives from several factors: insights gained from digital data, the automation of system solutions coupled with the active prevention of error sources, and the option of leveraging digital customer access to realize completely new ways to interact with users.[18]

17 See Patrignani, N./Kavathatzopoulos, I. (2016).
18 See Deutscher Bundestag (2014).

Digital systems of relevance to environmental technology and resource efficiency

Digitalization is increasingly evolving into an enabler of system formation, as the four keys to digitalization (digital data, automation, digital customer interfaces and connectivity) lay the foundation for innovative digital systems. At the same time, new products and services are being developed alongside innovative ways to use existing components. One thing the digital systems presented on the following pages have in common is considerable environmental relief potential. Environmental relief potential is understood to mean the extent to which using, applying or drawing on a product, process or service eases the burden on the environment. For example, renewable energies essentially possess substantial environmental relief potential with regard to climate action and energy consumption.

Specifically, the sections that follow address five digital systems: connected energy, connected information networks, Industry 4.0, urban connected mobility and smart grids. The exact content of each of these digital systems is defined, and a description of both incumbent and new companies and business models is followed by an assessment of economic and ecological aspects.

Connected energy

Buildings account for roughly 40 percent of Germany's total energy consumption. This figure includes the heating and cooling of rooms and the power consumed directly by appliances.[19] Improving the energy efficiency of buildings therefore plays a material part in lowering energy consumption and thus reducing emissions of greenhouse gases. One important tool to do so is energy management – not only in smart homes, but also in trade and industry, in retail and the service sector. Technological progress has changed buildings' role as energy-hungry consumers, and today they can also generate energy in the form of heat and electricity. Properties have morphed into energy "prosumers", in other words. This fact, coupled with growing connectivity, is making it possible to build the digital system known as connected energy (see Figure 70).

As a digital system, connected energy covers everything from the individual components of producers, stores and consumers of electricity to interaction with users, mobility and power utilities (blue elements; see Figure 70). Solar, wind and geothermal power plants are some of the options to generate power and heat. The generated electricity can either be stored in a power battery or consumed directly. Energy-efficient systems are available to optimize the producer's own consumption. For example, heat pumps and air-conditioning systems already use internal thermostats or can have their timing programmed by the user.

Where power can be neither consumed nor stored by the producer, links to the power grid open up the possibility of selling electricity on the market. The digital transformation is further strengthening connectivity between the individual components and their controllers (gray elements; see Figure 70). Here again, the four keys to digital transformation lay the foundation for the system.

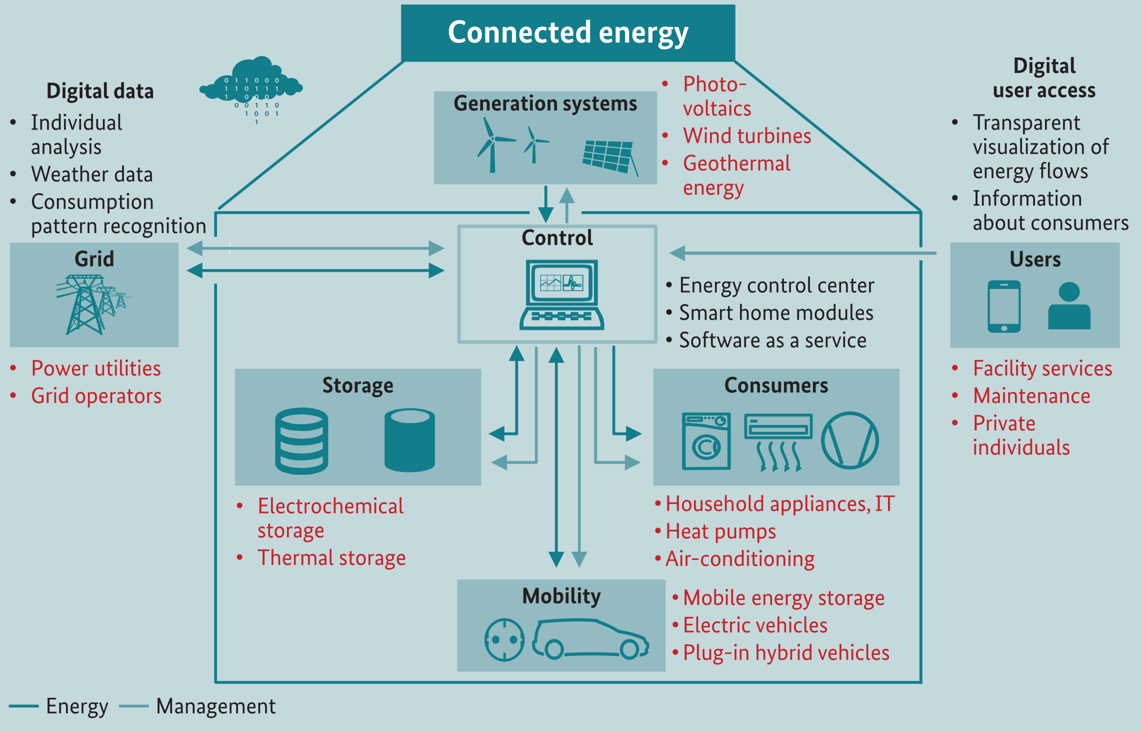
Connectivity across all components combines the smart generation, storage and consumption of electricity. The combination of connected photovoltaic installations and energy storage helps allow environmentally friendly energy to be used effectively. Storage units hooked up to the electricity market not only ensure that power is available when it is needed: They also facilitate better load management and optimized integration in the grid. Decisions about whether electricity is fed into the grid, whether mobile and stationary storage units are used or whether immediate consumption makes more sense are taken automatically.

Digital data is useful to understand users' consumption habits, optimize energy management and thus save on energy consumption. Weather data and consumption pattern recognition allow heating system control to be adjusted in such a way that thermal storage units are fully charged when the energy is actually needed. If no demand for heating is expected on account of the weather and users' habits, the energy can be put to other uses.

Automation creates a situation in which energy flows can regulate themselves. The need to operate heat pumps, valves, air-conditioning and ventilation systems (such as opening and closing windows) by hand is thus eliminated. Automation makes things simpler while also tapping additional potential to save energy. Digital user access enables information about a

19 See Bundesministerium für Wirtschaft und Energie (2014).

Figure 70: Components and structure of the digital system "connected energy"



Source: Roland Berger (2017)

building's energy systems to be gathered. This information creates transparency and cultivates awareness of the need to use energy responsibly. By visualizing energy consumption as a whole, it avoids focusing too narrowly on optimization measures that are limited to plant and equipment.

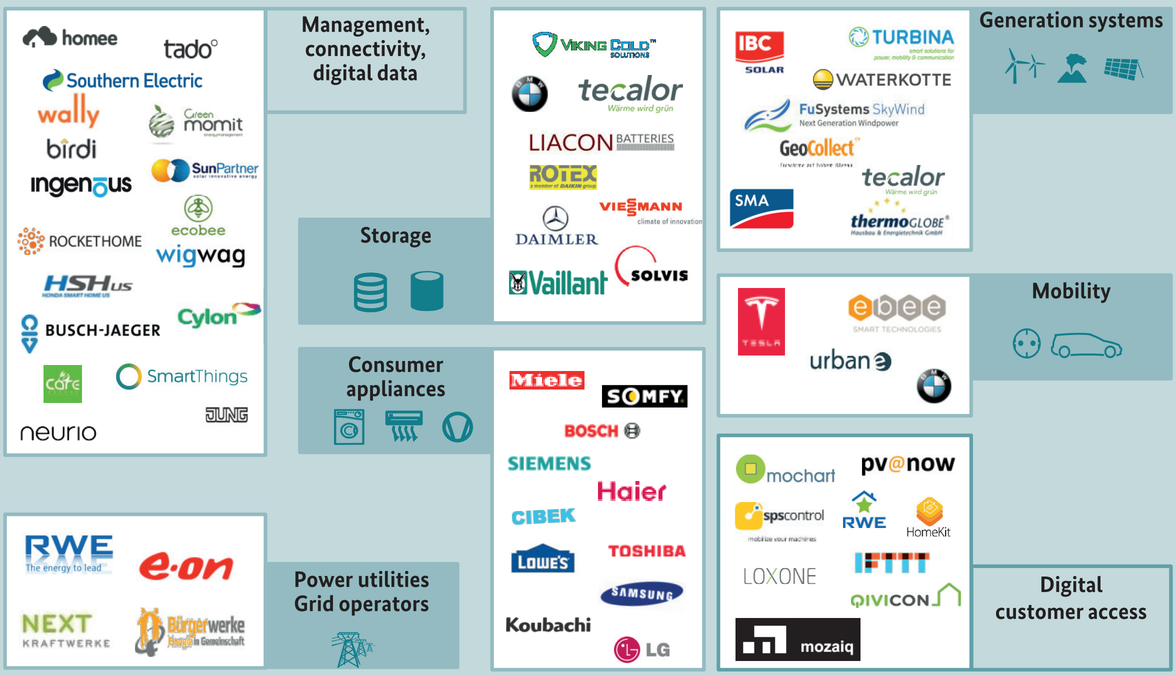
Companies involved in the digital system

The interplay of all kinds of components within the connected energy system demands completely different capabilities on the part of the actors involved (see Figure 71). Storage technologies, for example, are supplied by Vaillant and LIACON Batteries, whereas solutions to control and connect the individual components are core competencies of Southern Electric and homee. Firms such as Buderus and Viessmann provide consumer appliances, IBC produces photovoltaic systems and Ebee develops smart charging infrastructures. Many companies thus focus on sub-segments, leveraging specialization and detailed knowledge to gain competitive advantages.

The large number of players in the connected energy system also stand out for their heterogeneous nature. Companies from a broad spectrum of different industries converge within this system and, in the process, find themselves in a new competitive situation. Car makers such as BMW and Daimler are keen to build a new line of business in the orbit around storage technologies and are planning to sell new and used electric vehicle batteries as battery storage units for homes and for commercial use. Technology giants like Apple and Google are using their products Homekit and Nest to penetrate the market for the connected home, while IT service providers of the caliber of Deutsche Telekom and Cisco are staking out new positions with communication solutions for control equipment. Traditional power utilities are marketing management and connectivity options and, in so doing, are operating in parallel to developers of virtual power plants. The different backgrounds of these companies are a driver of digitalization in the connected energy system.

In this context, start-ups are occupying key positions in digitalization, often handling the tasks of establishing connectivity or managing data. They are thus exploiting the potential inherent in existing appliances. And by occupying this interface, these firms are positioning themselves as pivotal enablers of digitalization – even without developing technologies that are explicitly new.

Figure 71: The digital system “connected energy” – Segmentation and examples of players



Source: Roland Berger (2017)

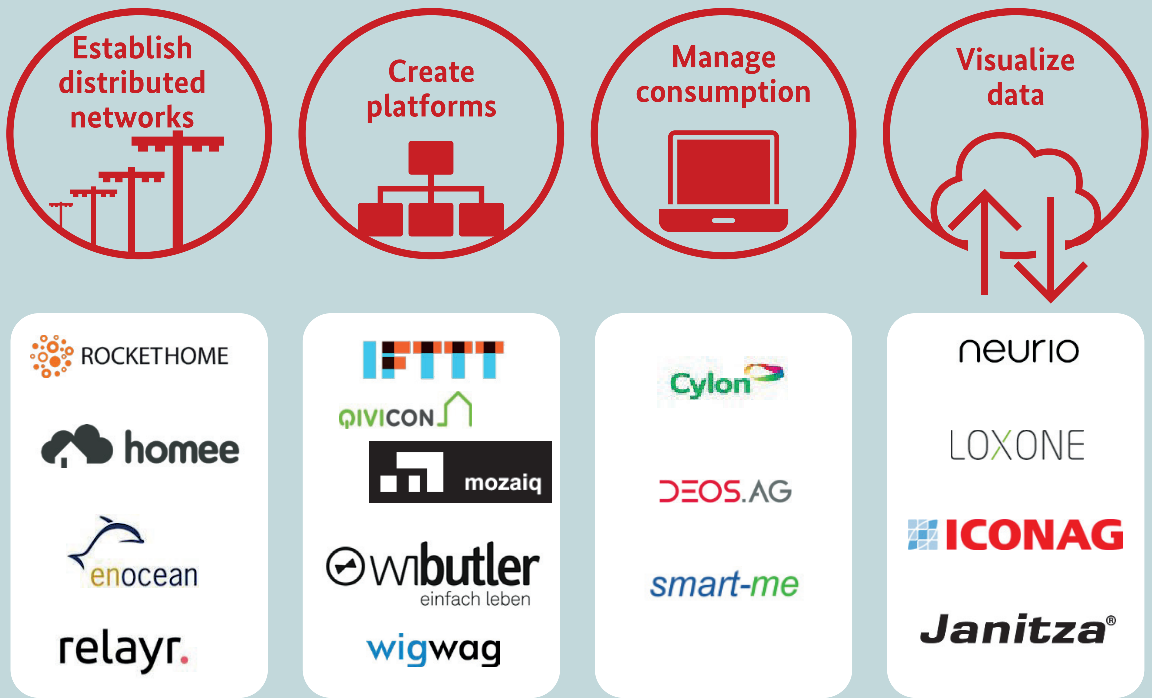
New business models

At every point in these digital systems, new business models are constantly springing up and being seized on by incumbents and start-ups alike. These business models indeed play a significant part in the creation of the digital systems and accelerate their continued development. The Figure below assigns (sample) companies that operate innovative business models to four categories: establishing distributed networks, creating platforms, managing consumption and visualizing data (see Figure 72).

Distributed networks must be established to enable components in the connected energy system to interact via transmission technology. Wireless technology company EnOcean markets battery-less wireless solutions in the form of switches and sensors.[20] The underlying idea is to use changes in energy statuses: Activities such as pressing a switch, changes in temperatures and having lights on all create the energy that is needed to transmit wireless signals. EnOcean’s products are deployed primarily in building automation and machine-to-machine (M2M) communication. The

20 See EnOcean GmbH (2017).

Figure 72: Examples of new business models that are driving digitalization in the connected energy system



Source: Roland Berger (2017)

company's vision is to develop tiny wireless modules that can be implanted straight into machine parts.

The platform business model uses connected sensors and devices to facilitate automated management. Businesses such as QIVICON bring multiple devices from different brands together on a single technical platform,[21] allowing the functions of different brands and devices to be combined, monitored, controlled and automated. QIVICON's partners include power utilities and various manufacturers of devices for use in the home and garden, as well as telecoms providers and suppliers of security solutions.

Energy management for buildings is offered by the likes of Cylon.[22] This company has developed an energy monitoring system called Active Energy SaaS, which, together with an open system for the integration of building management systems, is capable of operating an active energy management system. The toolkit includes a reporting function that forwards energy usage and consumption data in real time. The software is able to identify increases in power consumption by specific devices.

Intuitive data visualization is a fundamental precondition if the flood of data is to be made available to users and if management functions are to be readily comprehensible – and indeed possible in the first place. ICONAG rises to this challenge with four visualization products: a visualization editor, an alert system, digital time switches and graphical data loggers.[23] The visualization editor allows data points to be visualized in a tree structure. At the same time, users can draw on a library of symbols to design customized control software on touch panels, notebooks or mobile applications.

21 See Deutsche Telekom AG (2017).
22 See Cylon (2017).
23 See ICONAG Leittechnik GmbH (2017).

Building information networks

Analyzing material flows reveals the immensity of global resource consumption in the construction sector. Roughly half of the raw materials extracted worldwide – and 80 percent of mineral resources[24] – are channeled into the building industry. Buildings are not only erected, however: They are also torn down again, with demolition accounting for around 50 percent of the global waste volume. In other words, built-up infrastructure has a significant influence on the development of environmental and resource protection.

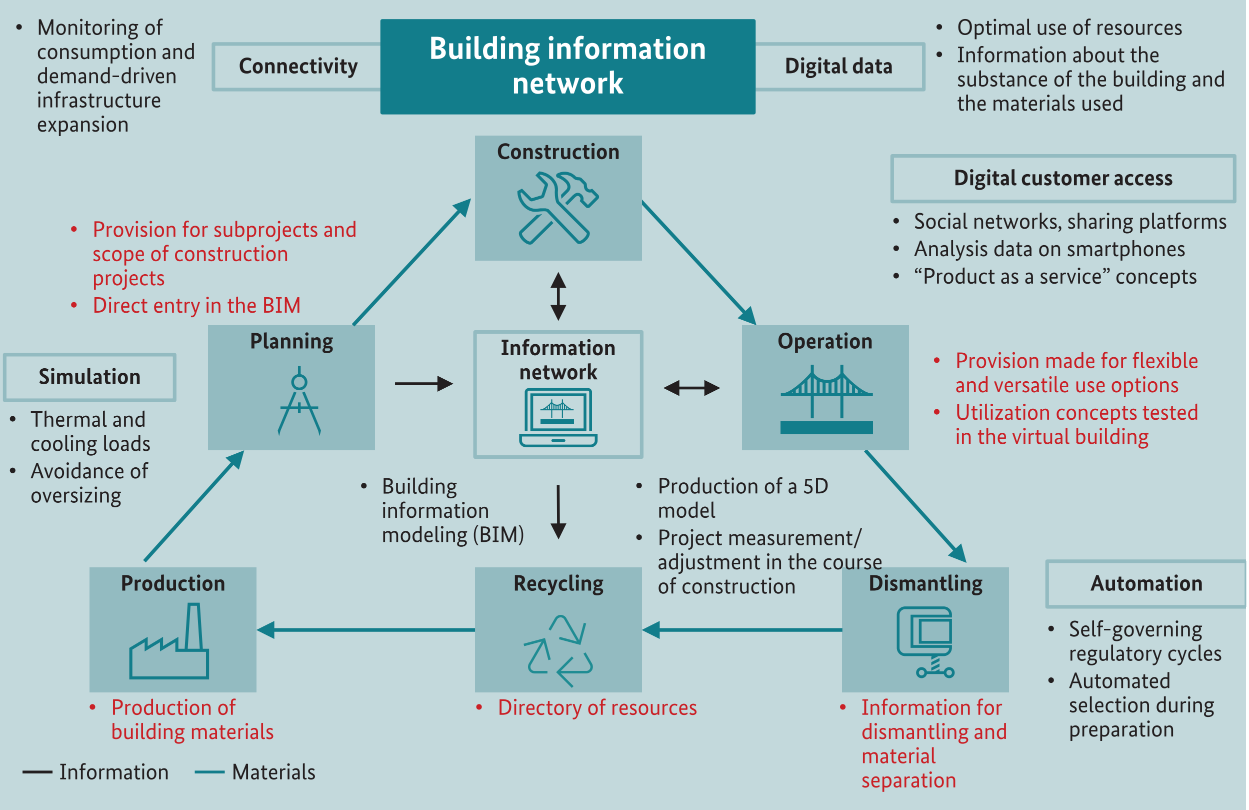
In Germany, too, construction accounts for a considerable proportion of material consumption. Every year, approximately 535 million tonnes of mineral resources are used to produce building materials and building products. Of this amount, stones and gravel account for about two thirds and sand for just under a quarter. The rest is split between lime, gypsum and other categories.[25]

Of the roughly 400 million tonnes of waste documented in the statistics for Germany, more than half (209 million tonnes) is made up of construction and demolition waste. While the recycling rate for this waste stands at 88 percent, only just over a third is channeled back into high-grade reuse.[26] Most recycled construction waste is used as filler material in the construction of roads and landfill sites.[27] Almost without exception, these input materials are thus "downcycled", i.e. converted into a poorer-quality end product.

Improving resource efficiency is the way to reduce resource consumption in the construction sector. The crucial factor is to increase resource productivity over its entire lifecycle, i.e. from planning through the production and selection of building materials to operation and, lastly, demolition or the recycling of built-up infrastructure.

Effectively increasing resource efficiency requires closer links to be forged across the entire value chain

Figure 73: Components and structure of the digital system "building information networks"



Source: Roland Berger (2017)

24 See SERI Nachhaltigkeitsforschung und -kommunikations GmbH (2012).
25 See Umweltbundesamt (2016a), page 14.
26 See Statistisches Bundesamt (2017d).
27 See Knappe, Florian / Lansche, Jens (2010).

in the construction sector, as well as the systematic capture and linkage of relevant data at each individual link in the value chain. Digitalization puts in place the conditions needed to do so, enabling the creation of a building information network as a digital system.

Digitalization within this system is driven primarily by connectivity between the various players and their products and services. Data from the planning, building material production, construction, operation and recycling phases is collected and analyzed systematically and made available to all relevant players in a suitably edited form. In effect, building information networks are a digital system that establishes digital connectivity between construction processes in a system that is rooted in data-based analysis of the entire property lifecycle (see Figure 73). A digital data model mirroring the property (i.e. a cyber-physical system) is the core of this digital system. Ideally, every player involved in the value chain – the owners, architects, structural engineers, construction authorities, facility managers, construction firms, building material vendors, demolition companies and recycling businesses – should have access to and be able to work with the central 3D model, including the information databases.

Driven by digitalization, the expansion of this particular digital system makes a significant contribution to increasing resource efficiency in construction. This becomes all the clearer when one considers the demolition of buildings: Building information networks supply copious information about the materials used, and therefore simplify the tasks of identifying and selecting high-quality resources during demolition work. They also make it possible to plan and implement the recycling of building materials with a sharper focus.

The incentive to improve resource efficiency begins with planning and material selection. Doing without complex composites and making special provision for recyclable building materials and removable structural elements create the conditions needed for higher-grade recycling and a further increase in the recycling rate.[28] Freedom from hazardous substances, too, is becoming a relevant and transparent selection criterion for building materials. The systematic ecological recording and evaluation of building materials is thus encouraging the transition to products and materials whose smaller environmental footprint places less of a burden on the planet's ecosystem. In particular, that involves the wider use of building materials based on renewable resources (in paints, varnishes and insulating materials, for example) and the conscious selection of building materials whose production uses especially material-efficient and energy-efficient methods. The benefits are twofold: While costs such as charges for the disposal of hazardous waste can be avoided, the built-up infrastructure can also serve as a store of materials for future projects. That would mark an important step toward realizing the cradle-to-cradle design approach in the construction and real estate industries.

Improvements in the planning process are another way to increase resource efficiency in the context of real estate. Digital building models permit the highly realistic simulation of the operating phase and ultimately supply very detailed information on actual thermal and cooling loads. This helps property developers to avoid oversizing structural and technical facilities and/or the expense and inefficiency of retrofittings.[29]

In the production of building materials, automation raises the proportion of recyclable materials. Smart robotics and sensor technology allow materials to be sorted, identified, separated and reused quickly and effectively.

During the operating phase, the building information network as a digital system yields further advantages: Here, potential efficiency gains can be realized by tailoring space to actual demand (digital land use planning), avoiding wasteful vacancy and activating predictive and condition-based maintenance and renovation.

28 See Lacy, Peter/Rutqvist, Jakob/Buddemeier, Philipp (2015).
29 See Bundesministerium für Verkehr und digitale Infrastruktur (eds.) (2015).

Companies involved in the digital system

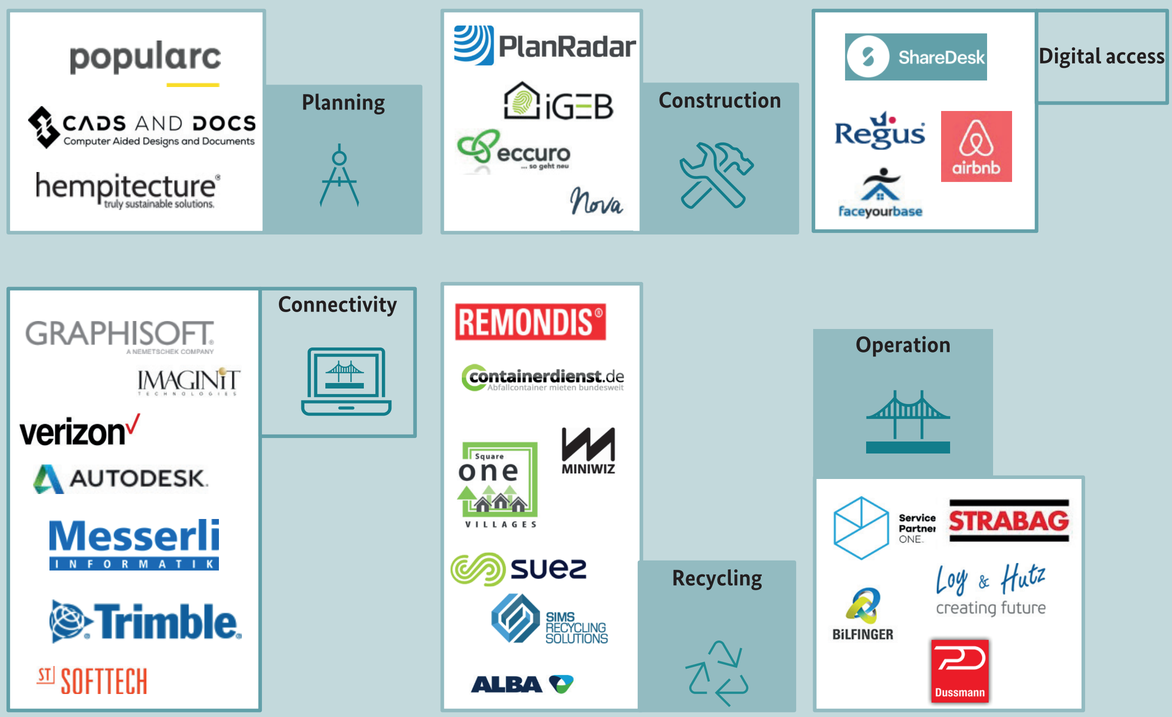
Every player at any point in the property lifecycle (see Figure 74) participates in the building information network as a digital system. Some players are incumbent firms that are expanding their portfolio to exploit the opportunities afforded by digitalization. During a building's operating phase, this primarily involves better maintenance services (based on remote control and predictive maintenance, for example) and enhanced energy efficiency services from facility management providers (with big data permitting the disaggregation of energy consumption). In the planning phase, more and more engineering consultants are drawing on more complex data models for the purposes of calculation and simulation. However, their contribution to connectivity and integration is essentially limited to their own link in the value chain and tends to lead to greater vertical integration.

New market players consciously adopt the function of central data management and enable horizontal connectivity. In this area, construction software providers (such as Softtech and Autodesk) find themselves competing with players from outside the industry – the likes of telecoms company Verizon and geodata firm Trimble.

In the recycling segment, traditional service providers such as Remondis, Alba and Suez play an active part and focus in particular on processing conventional construction waste. Innovative building material manufacturers that produce completely new materials from different types of waste make a major contribution to high-quality recycling. One such firm is Miniwiz, whose POLLI-Brick™ can be used to build walls from 100 percent recycled plastics.

Another group of start-up companies specializes in the digital modeling of complex industry-wide processes in the construction sector. PlanRadar, for example, uses digital technology to detect defects in buildings during the construction phase. It then systematically processes and monitors remedial work from initiation to acceptance.[30]

Figure 74: The digital system "building information networks" – Segmentation and examples of players



Source: Roland Berger (2017)

30 See DRS DefectRadar GmbH (2017).

New business models

The growing number of new market players is also adding to the array of services available. The development of new digital business models in particular is driving greater connectivity and deeper integration in building information networks (see Figure 75). By way of example, three fundamentally different approaches currently dominate the market environment: digital business models that result from data networking, “product as a service” strategies and innovative sharing concepts.

Joining up all data at every link in the property value chain opens the door to new services that concern themselves with the systematic capture, processing and provisioning of this data. Under the rubric “building information modeling”, solutions are developed that add the time and cost dimensions to three-dimensional building data.[31] What are known as electronic “material passes” containing information on pollution and reusability are integrated in these data models. The revenue models range from supplying and updating the software (license fees) to the graphical editing of the data models to consulting and planning services relating to the operation or demolition of the building.

Following the circular economy principle, the “product as a service” business model is a promising option for many firms and is again made possible primarily by digitalization. Products are no longer bought once, but are used as a service only for the duration of their actual service life. One good example is the “light as a service” approach which Philips uses to illumine Amsterdam’s Schiphol Airport.[32] Philips remains the owner of all fittings and installations, and Schiphol pays to use them. Thanks to digital data, only the exact consumption amount is billed. When the contract expires, all the fittings can be upgraded and put to another use, for example, or selectively recycled. Both alternatives significantly improve material efficiency. For Philips, the “product as a service” business model also opens up an attractively priced source for the future purchase of materials.

Figure 75: Examples of new business models that are driving digitalization in building information networks

Source: Roland Berger (2017)

31 See Eastman, C. (ed.) (2011).
32 See Philips (2015).

Sharing platforms take advantage of the new possibilities afforded by digital user access. These begin with digital contact initiation – for example between architects and developers, or between providers and users of space. Many platform providers make good use of the benefits digital media deliver in terms of flexibility, speed and the ability to keep data up to date. Here, the revenue model is based essentially on commission fees. Another approach arises from the modeling of digital workflows on specialist platforms that provide document management services in the planning and construction phase, for instance, or that take care of warranty tracking.

Industry 4.0

The manufacturing industry still plays a weighty role in Germany. Industrial companies generate 22.5 percent of the country's gross value added, and the export rate is 50 percent.[33] Manufacturing is also responsible for a good fifth of all greenhouse gas emissions in Germany.[34] Resource savings therefore have a huge impact in this pivotal sector of the German economy. Potential savings can be tapped above all by improving resource efficiency, which in turn can be achieved by optimizing the use of materials in production. Given the huge volumes of energy devoured by industrial production, there is also no shortage of opportunities to realize savings and improve energy efficiency. At the same time, in its capacity as the leading international industry supplier, Germany delivers plant and machinery for industrial production throughout the world. By the same token, it is also highly sensitive to technological trends in industry.

A powerful automotive sector, one of the driving forces behind the German economy, is itself rooted in the wider manufacturing industry. Large numbers of German midcaps have a global footprint. Some 1,500 of them stand out as "hidden champions", their specialized niche solutions occupying leading positions on the world's markets.[35] In mechanical and plant engineering and in automation systems, too, German providers lead the international field.

There is therefore no question about the impressive system solution credentials of German companies.[36] Especially in industry, digitalization is encouraging an ever more pronounced systemic approach driven by a number of players. Together, these players are developing new, innovative business models that have positive economic and ecological implications for the lead markets for environmental technology and resource efficiency.

Figure 76 illustrates an industrial production facility and its links to the outside world. Many components are already facilitating high productivity and greater resource efficiency in industrial production. Suppliers such as the producers of raw materials and traditional providers of intermediate products provide production facilities with materials to feed further production steps – the steps that transform the materials into goods. Traditionally, the consumers of industrial products are retailers, service providers, private individuals or other industrial customers who themselves use or refine the products they buy. In conventional industrial production, a variety of machines, sensors, robots and vehicles support the delivery, manufacture and logistical distribution processes, all of which are heavily standardized and automated.

Industry 4.0 is all about increasingly joining up humans, machines, equipment, logistical chains and products to form smart, digitally connected systems in which production can be largely self-organized and thus becomes more energy-efficient and resource-efficient. Connectivity in the context of Industry 4.0 raises production efficiency, thereby tapping into fresh potential to save energy and materials.

Digital data forms the basis for predictive maintenance. The modern sensor technology used to continually monitor the status of production equipment generates vast quantities of this data. Analyzing it then allows potential "trouble spots" to be identified and remedied before they cause disruptions. Lengthy outages or disruptions in the production facility can thus be prevented.

Thanks to the use of additive manufacturing processes under Industry 4.0, automation is continuing to advance. Additive manufacturing processes and lightweight construction methods are central to resource-efficient production in the context of Industry 4.0.

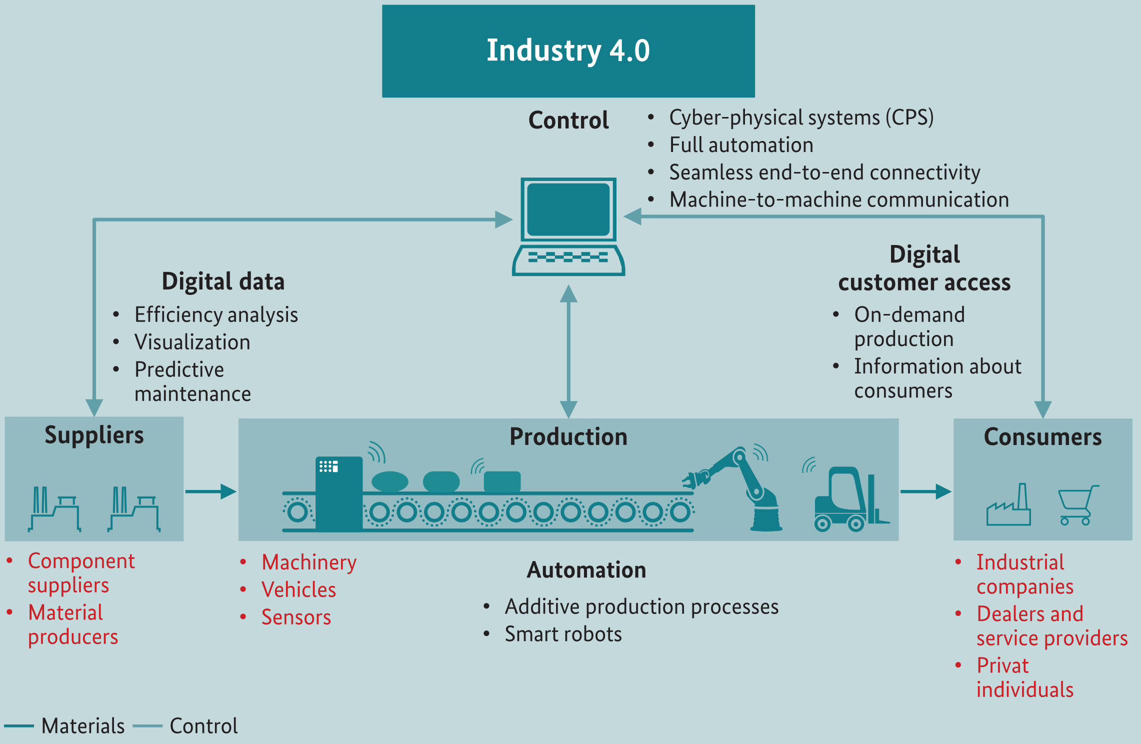
33 See Bundesministerium für Wirtschaft und Energie (2017f).

34 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017b), page 33.

35 See Deutsche Bank Research (2016), page 7.

36 See acatech – Deutsche Akademie der Technikwissenschaften e.V. (2013), page 5.

Figure 76: Components and structure of the digital system "Industry 4.0"



Source: Roland Berger (2017)

Special parts are 3D-printed on demand. Depending on the field of application, distinctions are drawn between rapid prototyping, rapid tooling and rapid manufacturing.

Digital customer access is reinforcing the trend toward on-demand production. Products are not made unless they will definitely be accepted by the customer. And that saves resources and energy, because direct, networked communication with the customer ensures that the production process consumes only and exactly what is needed to satisfy the customer's requirements. The products carry all the necessary information in themselves, and machines fitted with smart connectivity can adjust themselves automatically to varying product preferences.

These are not the only benefits that digital networking creates for Industry 4.0 production processes. If all information is accessible in real time, companies can, for example, respond earlier to the availability of certain materials. Across the entire enterprise, production processes can then be managed in a way that saves both resources and energy.

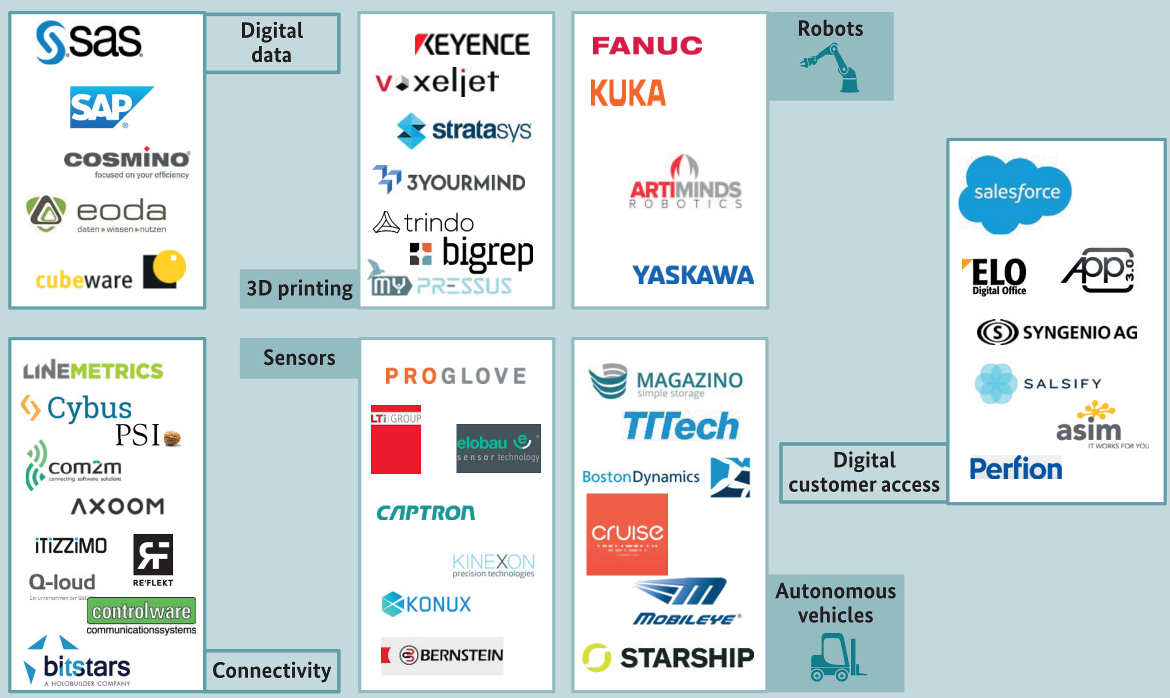
Companies involved in the digital system

Within the digital system "Industry 4.0", the implementation of digitalization affects all kinds of components and capabilities. Accordingly, a spectrum of widely differing players are rolling out suitable products and services (see Figure 77). Traditional technology firms and machine builders provide plants and individual components for production. Robot technology is supplied by incumbents such as Kuka and Fanuc. Companies like SAP and Cisco help to analyze the data that modern sensor technology from firms such as Elobau and Bernstein culls from the production plants. Businesses such as voxeljet and Keyence provide 3D printers for industrial production, while the likes of Com2m take care of interconnectivity between machines and products. To simplify digital customer access, Syngenio and Salesforce are two of the players that market cloud and software solutions for corporate customers. In addition, many firms specialize in individual niche areas in which each seeks to establish a competitive advantage.

Some of these firms are from other industries. But each one contributes the specific capabilities it has acquired in its own core market, extending its portfolio of products and services into the field of Industry 4.0. Apart from the large number of relevant companies, one characteristic feature of the "Industry 4.0" digital system is an ever increasing degree of homogeneity: Software providers like SAP and SAS today find themselves competing with companies such as Siemens and Bosch, which now no longer merely sell machinery but also IT solutions for Industry 4.0.

Meanwhile, start-ups armed with innovative offerings are launching an assault on – and occupying key positions in – the Industry 4.0 value chain. Munich-based Magazino is one of them, developing intelligent robots to handle the logistics of individual objects in the context of Industry 4.0. The devices and services developed by start-ups are powerful drivers of the ongoing dissemination of digital business models on the Industry 4.0 market. Many of them occupy positions in connectivity and data management. Innovative software solutions from firms such as Axoom, PSI and Q-loud leverage M2M communication to forge networks across the whole industrial production process. By occupying these important communication interfaces, start-ups position themselves as key drivers of digital connectivity in Industry 4.0.

Figure 77: The digital system "Industry 4.0" – Segmentation and examples of players



Source: Roland Berger (2017)

New business models

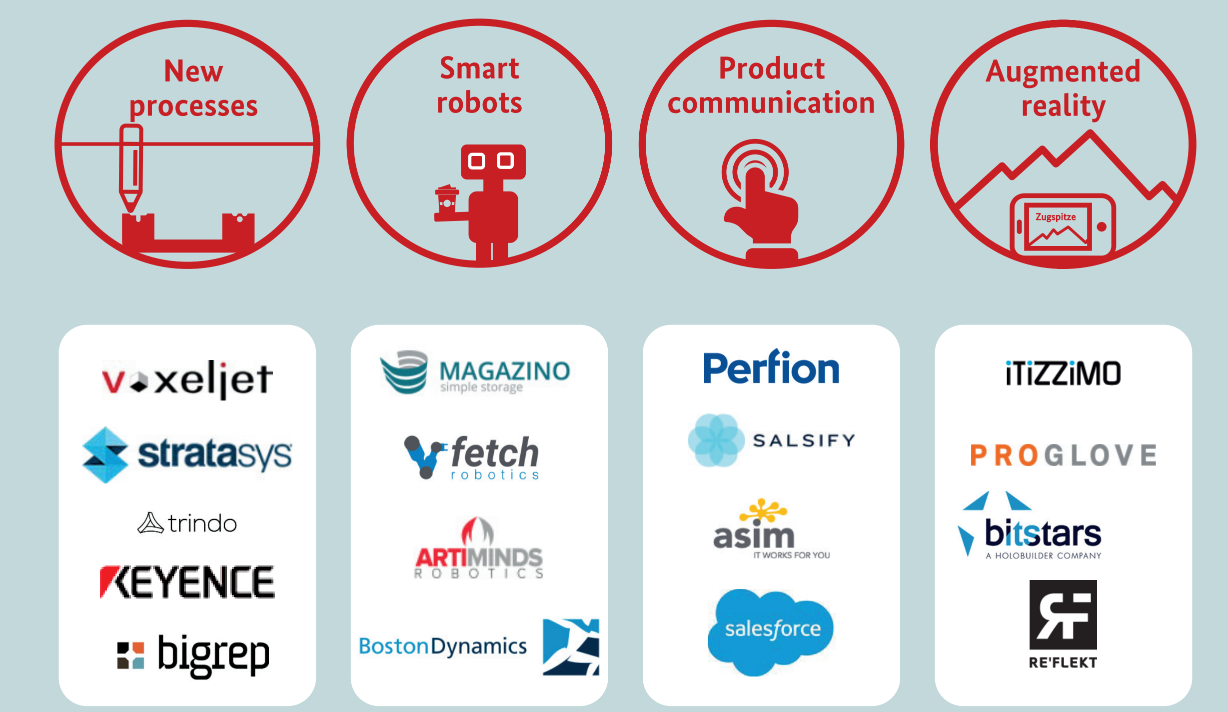
The challenges posed by the digital system "Industry 4.0" create opportunities for new business models (see Figure 78). These models exploit the potential of applications involving 3D printing technology, smart robots, the need for enhanced product communication and augmented reality that boosts production efficiency in order to generate revenue streams.

Louder calls for on-demand production are giving rise to business models that use 3D printers to produce small batches of components. Firms such as voxeljet hold out the promise of all kinds of customer benefits from 3D printing systems developed specially for industrial applications.[37] The tool-free and fully automated production of complex parts, prototypes and small-series components helps drive costs down. It also takes less time to produce parts than when traditional machine tools are deployed. Providers of industrial 3D printers generate revenue streams by selling 3D printers, but also by selling 3D printing as an outsourced service.

Business models based on smart robots are the solution to stepped-up demand for automation and adaptive, communicative machines in Industry 4.0. Start-ups such as Magazino are applying smart robot technology to new areas of application.[38] Their pick-by-robot solutions enable picking robots to be deployed in a way that complements the work done by humans. Production and logistics can thus be automated step by step. This approach also lowers the barriers to entry for customers, allowing automation to be implemented in gradual stages instead of all at once. Low capital expenditure costs combined with the prospect of lower labor and process costs are at the core of this business model.

The need for tailor-made production is bringing forth business models that are based on intelligent product communication.[39] Providers of product information management systems such as Perfion simplify communication between humans, products and machines by enabling the central, media-neutral visualization of data across multiple IT systems throughout the enterprise. Every machine and every worker thus has the specific product information they need available in an up-to-date form at any time. As a result, just-in-time production can be controlled with tremendous precision. Services such as real-time-based analysis via cloud networks are a pivotal aspect of these business

Figure 78: Examples of new business models that are driving digitalization in "Industry 4.0"



Source: Roland Berger (2017)

37 See voxeljet AG (2015).
38 See Magazino GmbH (2017).
39 See CPC Strategy (2015).

models, enabling research, purchasing, production and sales-related data to be used on multiple levels.

Other business models harness augmented reality to simplify communication between humans and machines. Start-ups such as Itizzimo[40] provide solutions for the digitalization of production processes, with human-machine interaction playing a key role. Examples include augmented reality devices and wearables such as ProGlove, a smart glove fitted with an RFID scanner, motion sensor and both haptic and visual feedback. The glove helps employees to use the right tools to complete the right work steps on the right products.[41]

Urban connected mobility

Germany's transportation sector accounts for just under a third of the country's total primary energy consumption and 17.7 percent of its greenhouse gas emissions.[42, 43] Nearly two thirds of traffic-related CO_2 emissions are attributable to private transportation.[44] These ratios single transportation out as a major target for energy-efficient technologies. Shortening the distances traveled by applying smart mobility management and reducing traffic congestion times are promising ways to lower energy consumption and cut the resultant emissions of air pollutants and greenhouse gases. At the same time, more must be done to incorporate alternative drive technologies in mobility concepts. While substantial amounts are set aside for investment in traditional infrastructure projects, the much-vaunted strategy of joining up transportation systems – which would make it easier to use different modes of transport – is still in its early days. Urban connected mobility is a digital system that passenger transportation (both the infrastructure and the vehicles) in urban areas. Within this system, a host of players are busily developing innovative business models.

The digital system urban connected mobility is made up of lots of individual components, Private individuals, companies and public institutions have access to various means of transportation, such as (shared or privately owned) cars and public transportation services. Bookings for individual means of transportation can be made separately, with (mobile) Internet offerings supported in the majority of cases. Individual guidance is also provided in the form of parking guidance and navigation systems. Existing transportation infrastructure elements (such as traffic lights) are equipped with sensors, while filling and charging stations permit cars powered by every conceivable drive technology to be used on a large scale.

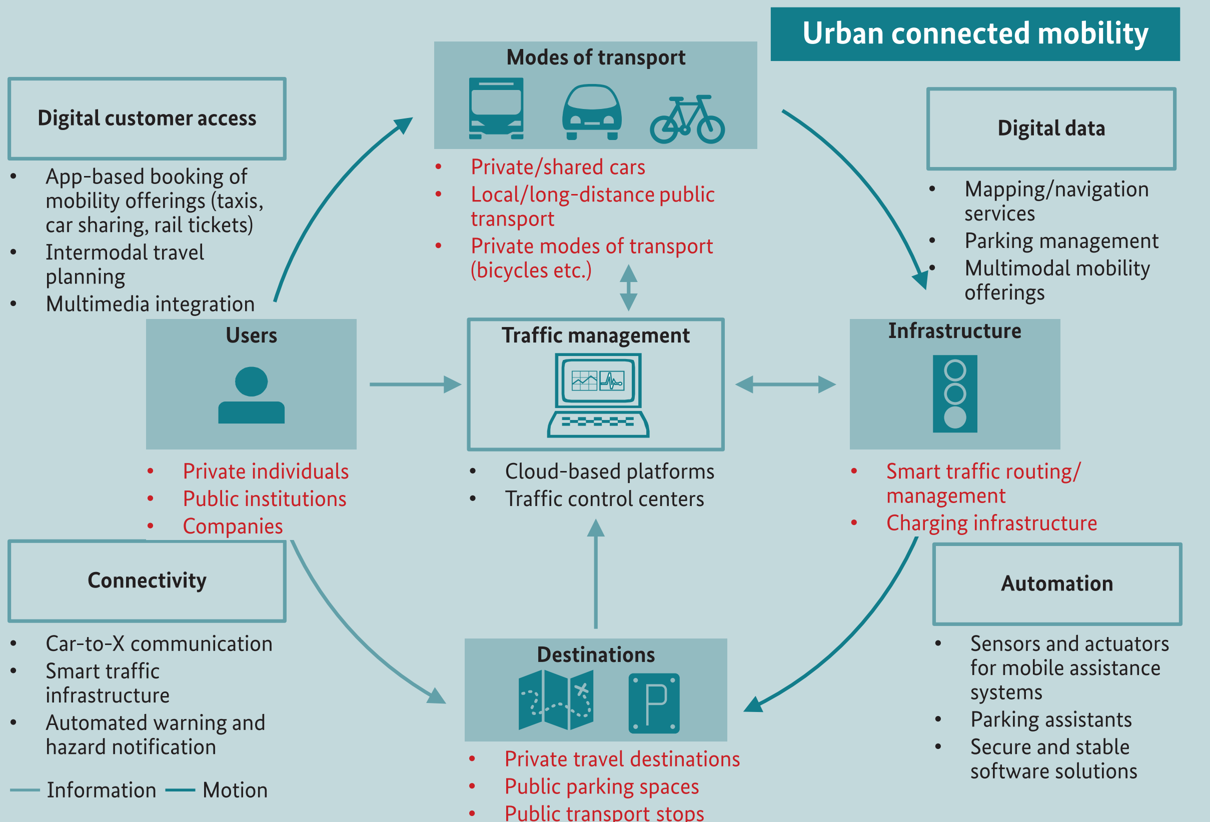
Digitalization brings these hitherto separate elements together, with virtual traffic management forming the core component. This is where data from users, means of transportation, infrastructure and destinations comes together to be processed and passed on. The management core analyzes information about mobility preferences and destinations and updates it in the system. Urban connected mobility can thus be built around the four keys to digital transformation.[45]

Digital customer access improves the use of multimodal mobility offerings. This is what makes it possible for private individuals, companies and public institutions to access innovative platforms. Ecofriendly forms of mobility such as bicycles, car sharing and local public transportation can serve as alternatives to motorized private transportation. Combining mobility offerings intelligently in this way not only creates efficient, multimodal ways for users to get around, but also helps reduce the volume of traffic on freeways, highways and, in particular, urban roads. If customers are to make use of environmentally friendly mobility offerings, however, those offerings – such as an attractive local passenger transportation system and cycle paths – must be there in the first place. If they are lacking, the danger is that the opposite effect will materialize: Local passenger transportation customers could, for example, switch to car sharing and thus exacerbate the burden on the environment. This realization highlights the fact that digitalization must be flanked by suitable conditions if environmental relief potential is to be tapped.

Digital data helps mapping and navigation services to adjust routes in response to the current traffic situation. If factors such as changed orders for commercial transportation and real-time traffic conditions are taken into account, route guidance can be planned more efficiently.

40 See ITIZZIMO AG (2017).
41 See Workaround GmbH (2017).
42 See Arbeitsgemeinschaft Energiebilanzen e.V. (2016).
43 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017b), page 37.
44 See Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017c).
45 See Wolter, Stefan (2012).

Figure 79: Components and structure of the digital system "urban connected mobility"



Source: Roland Berger (2017)

Rigorous use is made of interconnectivity to identify traffic situations. Large numbers of sensors and mobile devices as well as connected cars play a part in painting an accurate picture of traffic volumes. The use of sensors and cameras in and around streets and roads is an important aspect of this approach.

As automation gains ground, driver assistance systems too are growing in significance. Parking assistants are one of the most important areas of application, as they will in future mean that less space is needed for car parking facilities. Assistance systems are constantly being improved and touch on one of the principal topics for the automotive industry: autonomous driving. If systematic development of data, connectivity and automation continues and if use is made of these advances, self-driving vehicles should be on the roads as of 2020.[46] This technology would open up all kinds of new potential mobility applications: individual transportation services, traffic flows optimized seamlessly from end to end, precise congestion forecasts and accident avoidance, for example.

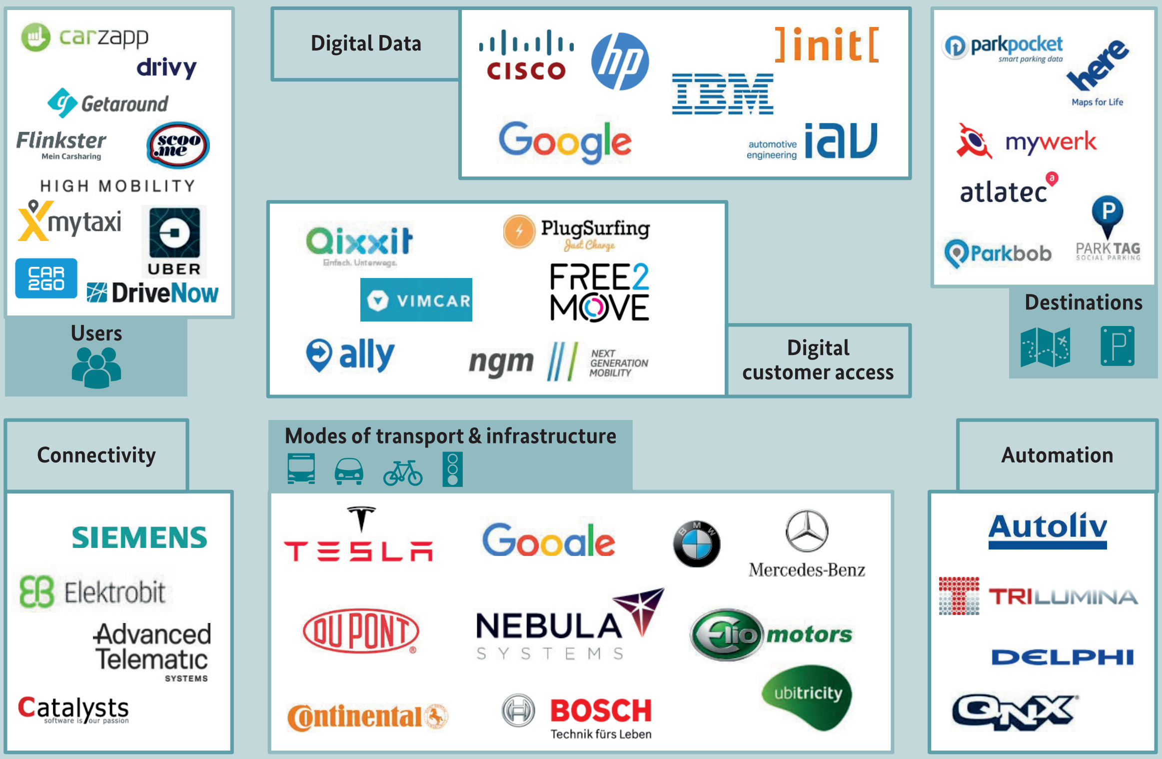
46 See Unattributed (2016).

Companies involved in the digital system
The many facets of this digital system are reflected in the large number of companies that operate on this market (see Figure 80). Solutions for parking management are marketed by firms such as Parkpocket and ParkTAG, while Cisco and HP play an active role in the field of digital data. Carzapp and Getaround focus on user access, whereas QNX and Delphi are advancing the automation of mobility. Similar to what we have seen with the other digital systems, urban connected mobility is thus shaped by a singular diversity of specialized companies – a fact which explains the considerable number of players.

As with the other digital systems, the varying backgrounds of the companies involved are again a striking feature. Sharing providers such as Scoo.me and Drivy are competing with transportation companies such as MyTaxi and Uber. Via the subsidiary companies DriveNow, car2go and Flinkster, automotive OEMs such as BMW and Daimler are now also committed to this segment, as are traditional mobility service providers like Deutsche Bahn. Additionally, automotive suppliers Continental and Bosch, sensor company Trilumina and telecoms firm Cisco all provide smart solutions for vehicle connectivity. In the race to interconnect individual components, industrial conglomerates of the caliber of Siemens line up against niche specialists such as Elektrobit. At the same time, card services such as Here and Atlatec are fighting Parkbob and other service providers to secure market share.

Start-ups like Quizzit, Carjump and Plugsurfing assume a key role in the digital system urban connected mobility. Cloud-based user connectivity, mobility offerings and infrastructure put them at the strategic nodes of digitalization, where they drive the development of digital business models. In the individual segments, this role positions them as the link tech-heavy firms and customers. It also lets them benefit from comparatively low investment and development costs.

Figure 80: The digital system "urban connected mobility" – Segmentation and examples of companies



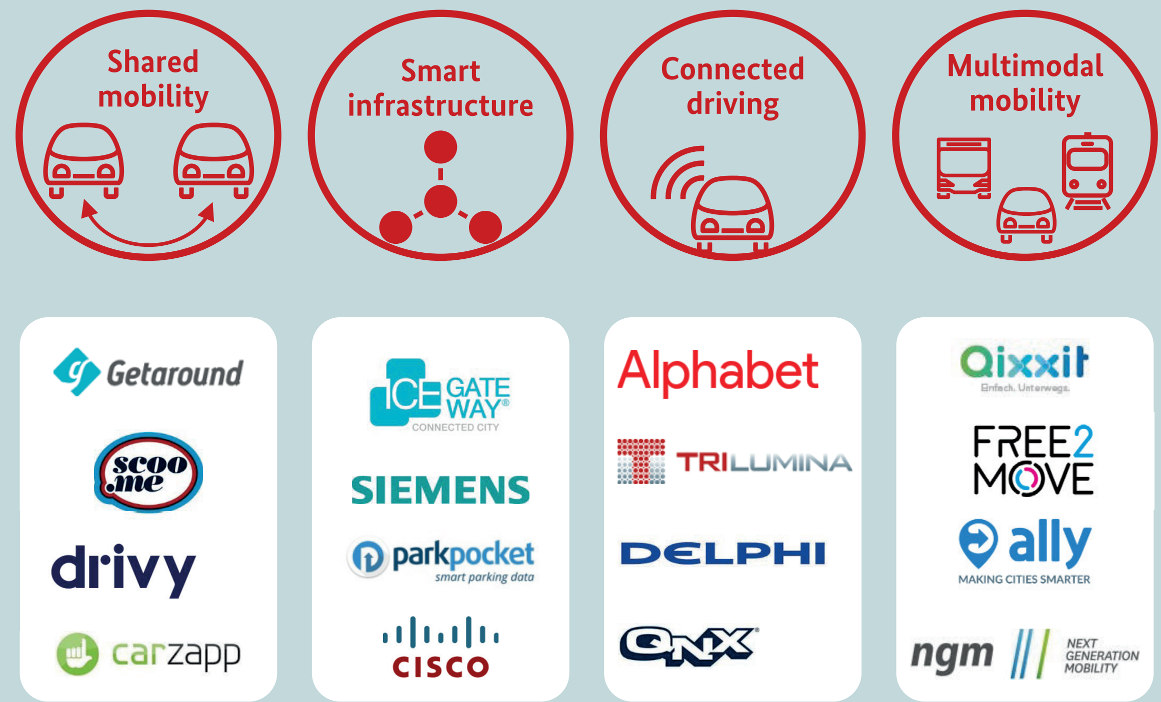
Source: Roland Berger (2017)

New business models
Taking advantage of the heterogeneity that prevails in the digital system urban connected mobility, innovative companies are introducing disruptive business models and breaking up existing structures (see Figure 81). Car sharing, smart infrastructures, connected driving and multimodal mobility in particular create openings for new business models.

The shared mobility business model is made possible first and foremost by using mobile apps to establish basic digital connectivity between customers and sharing platforms. It is hoped that the concept of "sharing" vehicles will fundamentally reduce demand for owned cars. When a car is needed, it can be booked out of a car pool and made available for the required period. Car sharing providers such as car2go and DriveNow are subsidiaries of auto makers that are using their existing capacity in particular to stock these vehicle fleets. Start-up players like Drivy and Getaround seek to broker the availability of private vehicles: Customers can use vehicles owned by private individuals in the neighborhood who currently do not need them, freeing the provider from the need to purchase a car pool.
Smart infrastructure business models are facilitated primarily by the opportunities that sensors and control systems create for digital connectivity. In the field of connected traffic management, Cisco is one of the IT service providers contributing its expertise in digital networks and computer-based analytics.[47] The company sells solutions that work with secure connections between two vehicles and between vehicle and infrastructure. These solutions require the capture, processing and transmission of data about road signs, road conditions, the weather (where appropriate) and traffic. They make it easier for local governments to comply with statutory thresholds for urban emissions. Self-optimizing traffic light controls also reduce traffic congestion.

In connected driving, digitalization paves the way to new business models by creating mobile communication systems. Software vendor QNX, for example, develops stable IT platforms with vast computing power for the automotive industry.[48] These products are used to integrate information, assistance and multimedia

Figure 81: Examples of new business models that are driving digitalization in "urban connected mobility"



Source: Roland Berger (2017)

47 See Verband der Automobilindustrie (2017).
48 See QNX Software Systems Limited (2017).

systems and thus serve to weave vehicles more deeply into the fabric of the digital mobility environment. The multimodal mobility business model, too, would not be conceivable without digital platforms. Integrated cloud-based offerings provide an overview of the various mobility services that are available. Mobility start-up Qixxit is a pioneer in this field: Via a web platform, its users are presented with various options for getting to their chosen destination.[49] The alternatives take account of modes of transportation such as private cars, car sharing, buses, trains, hired bicycles and even walking. Users also see how much each alternative would cost and how long it would take. Even after booking one of the options, the app accompanies them through their journey. This kind of integrated offering simplifies the decision process for consumers, makes switching to environmentally friendly mobility offerings more straightforward and is, for precisely this reason, important wherever a complex mix of transportation offerings exists.

Smart grids

In 2016, renewable energy accounted for 29 percent of gross electricity production – i.e. of all the electricity produced in the whole of Germany.[50] The aim is for renewable energy to cover 40 to 45 percent of Germany's demand for electricity by 2025, with this figure rising to at least 80 percent by 2050. If these federal government targets are to be hit, the energy industry infrastructure must be adapted accordingly. One of the biggest challenges is to hook up distributed power generation plants and – as well as expanding the available storage options – plugging them into the power grid. The stability of the transmission grid must be safeguarded by maintaining stable voltage and frequencies and avoiding overloads. To guarantee the stability of the grid – and thus ensure a reliable power supply – the power fed into the grid and the power drawn from it must be in equilibrium at all times. Since the grid itself cannot store energy, other mechanisms are needed to balance production and demand. That is done via the frequency of AC voltage, which must be kept at 50 Hertz with only narrow tolerances. In light of this situation, managing the power grid is becoming an increasingly complex challenge that can be mastered only with the aid of digital technologies. Digitalization allows a growing information network to complement the power grid, creating the digital system referred to as a "smart grid".

A large number of individual components and technologies are already in active service in the smart grid digital system (see Figure 82). Conventional power plants and (centralized and distributed) producers of renewable energy feed power into the existing grid infrastructure. Transformers bring the voltage into line with the needs of industrial and private consumers. The required capacity is adjusted and the control power supply is tapped in response to demand. If the supply of energy occasionally exceeds demand, central energy stores such as pumped storage hydropower plants can absorb the surplus and discharge this energy again later on. Distributed, battery-based storage options (in electric cars, for example) and, in particular, hydrogen and "power-to-x" technologies are also available.

Digitalization helps reinforce the systemic approach. The four keys to digital transformation open up completely new ways to integrate renewable energy and other energy producers.[51]

Joining up nodes in smart grids as a digital system allows data to be gathered and individual players to be connected to these grids. Distributed "prosumers"[52] thus become part of the system, and the power they feed in can be distributed appropriately.

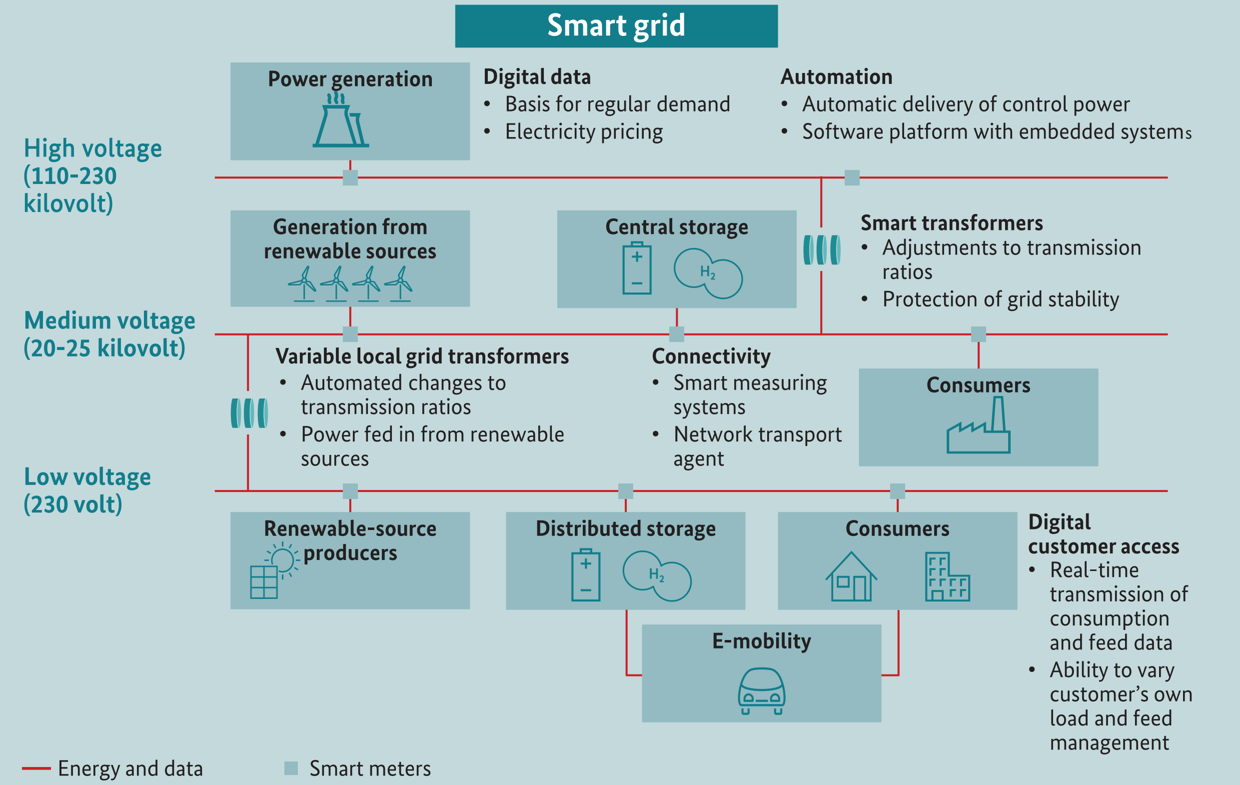
49 See QT Mobilitätsservice GmbH (2017).
50 See Bundesministerium für Wirtschaft und Energie (2017a).
51 See E.ON Energie Deutschland GmbH (2017).
52 "Prosumer" is an artificial word that combines the terms "producer" and "consumer" – in this case in the context of power generation and power consumption.

Thanks to digital customer access, the various users of smart grids can keep track of their own consumption, compare it with that of others and make adjustments where necessary. Users can also access their own load and feed-in management system: When weather conditions or electricity prices are favorable, the settings can be adjusted accordingly. Energy performance and energy efficiency can be evaluated, too.

Analysis of the digital data generated by consumers, storage units and producers is one of several fundamental prerequisites if a smart power grid is to work. Regular demand is calculated on the basis of this data, allowing decisions to be made about feed-in processes and load determination. Ultimately, the digital data is also used to set electricity prices for consumers and producers alike.

The automation of power management processes is especially useful in that it simplifies the integration of prosumers in smart grids. If defined parameters such as a given electricity price, level of demand and the prosumer's own production surplus are reached, for example, then power is automatically fed into the grid. Conversely, suitable technology can also trigger the automatic delivery of control power or automatically add power from conventional producers.[53]

Figure 82: Components and structure of the digital system "smart grids"



Source: Roland Berger (2017)

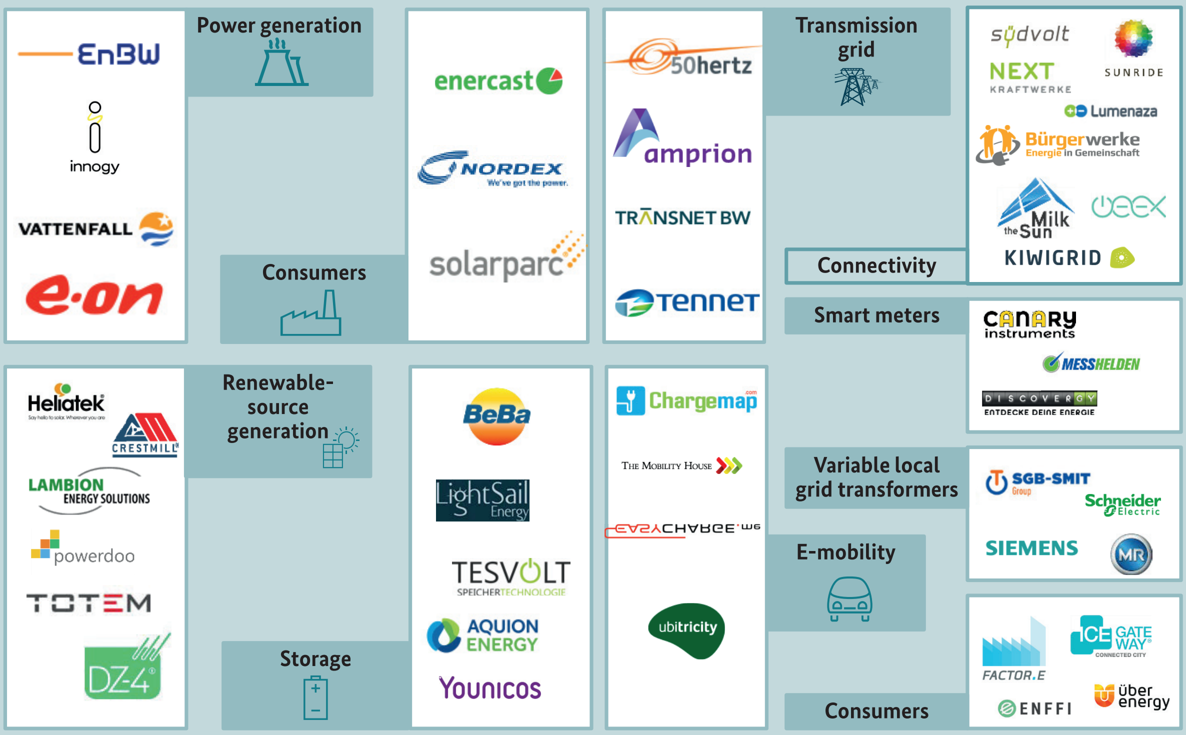
53 See Fraunhofer-Einrichtung für Systeme der Kommunikationstechnik ESK (eds.) (2011).

Companies involved in the digital system
Numerous entities are keen to secure their share of the power generation and distribution value chain (see Figure 83). Predominantly conventional power producers such as E.ON and RWE[54] and producers of renewable energy such as Crestmill also operate on the market, as does smart meter provider Canary. Sunride and Lumenaza develop connectivity products, while Nordex and Enercast specialize in applications for industrial consumers. The sheer variety of solutions that are needed to create a smart grid is the main reason why so many players are actively involved in this market.

The heterogeneous nature of all these products is also the reason why so many different industries come together in this digital system. Players from other sectors are discovering potential in the power grid market and putting their specialized technological expertise to good use. Industrial giant Siemens develops its own variable local grid transformers. In so doing, it finds itself competing with SGB-SMIT, a special-purpose transformer company that manufactures large-scale transformers for applications with up to 800 Kilovolts, for example. As a complement to central power plants, incumbent energy companies such as E.ON and Vattenfall are now also marketing a wide range of distributed plants, including biomass, cogeneration and photovoltaic installations, all of which are available as system solutions. In the process, they are increasingly moving into a niche hitherto occupied by specialists such as Lambion and Totem.

Start-ups are an important driver of smart grids, delivering the digitalization that this digital system needs. These players use Internet-enabled products and cloud-based applications to develop completely new services for the smart power grids of the future. By identifying and exploiting the many possible applications for smart solutions, these companies are preparing the way for the digital transformation. They are doing so by using their own products to dock existing products from technology and industrial companies onto existing structures.

Figure 83: The digital system "smart grids" – Segmentation and examples of companies



Source: Roland Berger (2017)

54 RWE spun off its renewable energy, network and retail businesses in Germany and abroad to form a separate entity initially called RWE International SE. The subsidiary now operates under the name innogy SE and has been publicly traded since October 7, 2016. E.ON carved out its energy business, which focused on conventional power generation and electricity trading. Since September 12, 2016, shares in Uniper have been traded on the Frankfurt Stock Exchange. The "new" E.ON focuses on customer networks, customer solutions and renewable energy.

New business models

Digitalizing the power grid opens the door to new business models for smart storage technologies and effective load management solutions (see Figure 84) developed by both incumbents and start-ups. These models are instrumental in building digital systems and accelerating their ongoing development.

Mechanical, electrical and industrial electrochemical energy stores create brand-new ways to balance loads and thus allow renewable energy to be hooked up to the grid. Thermodynamics company LightSail Energy, for example, is developing storage solutions that combine air compression with simultaneous thermal storage. Younicos specializes in large-format battery technology and is building battery storage power plants. These battery parks can be made ready for operation about 3,000 times faster than conventional power plants, so they can provide primary control power cost-effectively. This, too, simplifies the integration of renewable energy in existing electricity grids.

The conditions needed for the electricity marketing business model are put in place as digitalization establishes smart networks across feeders and grids. Lumenaza's business is built around a software platform that serves as a marketplace for electricity producers and consumers.[55] The technology uses algorithms to optimize the distributed power plants in a given region, striking a balance between the generation and consumption of power. Storage systems play an important part in this solution, absorbing excess electricity when supply exceeds demand. Regions thus gain greater independence and have to buy less power on electricity exchanges. Lumenaza has also developed a control gateway that can manage local generation and consumption plants. The company is thus able to do everything a traditional power utility would do in the form of a service.

The decentralization of prosumers that is facilitated by digitalization prepares the ground for new business models for the use of virtual power plants. Small and

Figure 84: Examples of new business models that are driving digitalization in "smart grids"

Source: Roland Berger (2017)

55 See Lumenaza GmbH (2017).

medium-sized distributed power producers such as wind farms, solar farms, hydroelectric power plants and biogas installations together constitute a single virtual power plant. Firms such as Next-Kraftwerke take advantage of the fact that electricity is not always traded at the same price.[56] Thousands of members of a virtual power plant benefit from this circumstance by producing and consuming electricity at times when it makes sense for the whole system. Network effects generate the critical mass needed to operate on the various electricity markets.

As a digital system, smart grids also need effective network management to oversee the complex interplay between their different components. Above all, the need to integrate energy transition technologies (heat pumps and e-mobility etc.) in the system is placing new demands on urban power grids. To rise to this challenge, companies have implemented an array of solution strategies in different business models. Kisters harnesses its software engineering expertise to roll out solutions that help optimize the generation, distribution and use of energy. Other firms, such as Kiwigrid, adopt a holistic approach and provide both software and hardware for smart grid management as a flexible, open and adaptable gateway to the energy cloud.[57] That in turn facilitates alignment between the individual grid components.

56 See Next Kraftwerke GmbH (2017).
57 See ZAE Bayern (2017).

Effects and potential of digitalization in the green tech industry

The economic potential of digitalization

Environmental technology and resource efficiency are already a fast-growing market. Digitalization can further accelerate expansion in this sector: The synergies and system effects arising from the expansion of digital systems will probably lead to stronger demand for environmental technology and resource efficiency products, methods and services.

Current calculations forecast that digitalization will add more than 20 billion euros to Germany's green tech industry in 2025 – three percent of the total market volume forecast for the same year. The individual lead markets will, however, make varied contributions to this potential (see Figure 85). Digitalization will add the least growth in the lead markets for sustainable water management and material efficiency.

Energy efficiency, the biggest of the six lead markets, should see the strongest impact on its absolute volume, with digitalization adding 7.2 billion euros in 2025. Digitalization also harbors substantial growth potential of 4.2 billion euros in the lead market for environmentally friendly power generation, storage and distribution. The lead market for sustainable water management is predicted to reap the smallest volume increase of only 0.8 billion euros from digitalization in 2025, a figure that also equates to the smallest proportional market growth of just 1.9 percent. The focal point of this lead market is on infrastructure whose long service life means it will only be penetrated slowly by digital developments.

The sections that follow draw on technology lines and the keys to digitalization to analyze and explain the drivers in the individual lead markets.

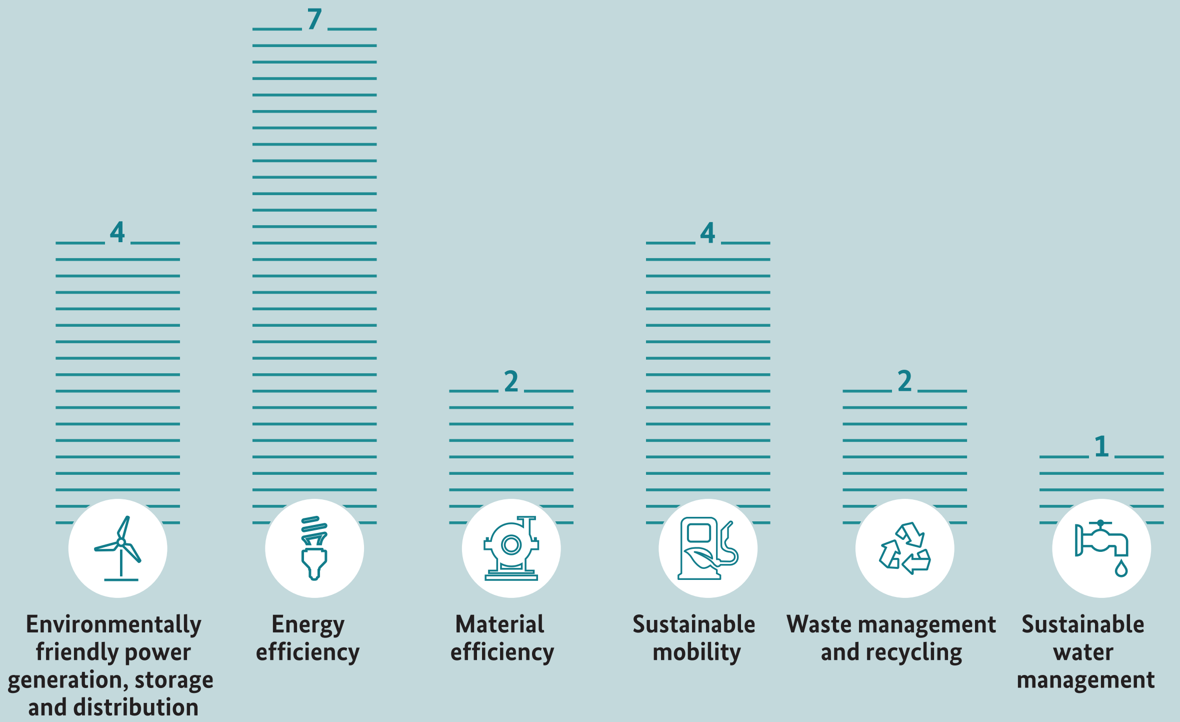
Methodology: Calculating the economic and ecological effects

This section discusses the extra market volume that digitalization is expected to add to the market for environmental technology and resource efficiency. This volume was calculated using Roland Berger's market model, which takes the various technology lines (products, processes and services) as its starting point. From the bottom up, the technology lines are aggregated to calculate the size of the market segments and lead markets (see page 47).

The five digital ecosystems outlined below cover the lion's share of those aspects of the overall market for environmental technology and resource efficiency that are affected by digitalization. Economic and ecological analyses of the digital ecosystems can therefore be taken as the basis for calculation and – after being broken down to the market segment level – extrapolated for the market as a whole.

All calculations are based on assumptions rooted in the current legal framework, technology that is available today, existing players, emerging business models and the historic dynamics of innovation.

Figure 85: Volume that digitalization can add to the lead markets for environmental technology and resource efficiency in Germany in 2025 (billion euros)



Source: Roland Berger (2017)

The lead market for environmentally friendly power generation, storage and distribution
Between 2016 and 2025, the lead market for environmentally friendly power generation, storage and distribution will grow from 79 billion euros to a total volume of 135 billion euros. That works out at total market growth of 56 billion euros, or an average increase of 6.2 percent every year for the next nine years. If the effects of digitalization are factored in, an extra 3 percent should be added to growth in this lead market in 2025, bringing the overall lead market volume to 139 billion euros (including stimulus from digitalization).

Rising volumes in the technology lines renewable energy, electrochemical storage and control instrumentation for grids will be responsible for the market volume added by digitalization. One main driver of growth is connectivity between plants that store and generate energy, which will make distributed solutions more attractive in economic terms.

Renewable energy sources play an essential role in power generation. Digitalization will add 1.7 billion euros to the market volume in the renewable energy segment in 2025. Photovoltaic installations and wind turbines will play an especially important part, as connectivity is allowing them to be operated in ever more distributed and efficient configurations. In storage technologies – a segment where digitalization will increase the market volume by 1.5 billion euros (9 percent) – electrochemical storage systems are the way forward. These systems are deployed in conjunction with distributed renewable energy, and analysis of consumption and generation (or charge and discharge) data is making them ever more important as a component of smart grids. The latter are closely interconnected with the control technologies for grids and the metering/consumption measurement systems technology lines. As such, they also constitute a physical link between smart grids and both internal and external networks. The 1.3 billion euros (16 percent) added to the market volume by digitalization brings the total market volume to 10 billion euros for the efficient grids market segment in 2025.

The lead market for energy efficiency

Digitalization can cause the lead market for energy efficiency to grow by a further 4 percent in 2025. The extra 7 billion euros added by digitalization would come on top of a volume of 182 billion euros in 2025. The lead market for energy efficiency will thus see the strongest digitalization-driven growth in absolute terms. The market segments for energy-efficient production processes and cross-sector components in particular will see more growth on the back of digitalization. Thanks to the ability to recognize consumption patterns and interconnect key production components, digital data can tap into vast reserves of efficiency potential – reserves that can in turn be optimally exploited by digitalized environmental technology and resource efficiency systems.

Of all the market segments, energy-efficient production processes will experience the strongest relative growth. Digitalization can boost this segment's market volume by 0.6 billion euros (19 percent) to 3.5 billion euros. One driver will be increasing industrial automation due to digitalization. The same driver will also affect the market segment for cross-sector components, which includes technology lines such as electric drive systems in production plants. In 2025, digitalization will increase this, the largest market segment in volume terms, from 100 billion euros to 105 million euros.

The market segments for energy-efficient buildings and appliances will likewise be affected by the keys to digital transformation. Both will see a 3 percent increase in market volume in 2025 (1.3 billion euros and 0.9 billion euros respectively) as a result of digitalization.

The lead market for material efficiency

Between 2016 and 2025, the lead market for material efficiency will grow by 92 billion euros to a total of 155 billion euros, equivalent to average annual market growth of 10.5 percent. If the additional potential afforded by digitalization is taken into account, an extra 1.9 percent will be added to this figure in 2025, raising the total volume for this lead market from 155 billion euros to 157 billion euros. Alongside the automation of production processes, another factor here will be digital planning, which will promote the use of new, environmentally friendly materials and improve material efficiency.

A glance at the individual market segments shows that digitalization will raise the market volume for material-efficient processes from 18.6 billion euros to 20 billion euros in 2025. This segment centers around optimizing all production processes for plastic products, metal products and other materials. The technology line for processes in the building industry (structural engineering and building completion) is another mainstay of the segment. This market can grow by 0.8 billion euros (32 percent) due to the impact of digitalization. Moreover, it also enables more renewable resources to be used in construction and production. Digitalization is expected to add 0.4 billion euros (9 percent) to the total volume in the market segment for renewable resources, primarily because of growth in the high-potential technology lines for paints and lacquers from renewable resources and natural insulating materials. Thanks to digitalization, the volumes for these two lines will increase by 20 percent and 11 percent respectively by 2025.

The lead market for sustainable mobility

Between 2016 and 2025, the lead market for sustainable mobility will grow by 83 billion euros to a total of 157 billion euros. Annual market growth will average 8.8 percent over the whole of this period. Factoring in the effects of digitalization would add 2.1 percent to the volume for this lead market, raising the total from 157 billion euros to 160 billion euros in 2025.

This extra volume is essentially attributable to changes in individual motorized transportation and the resultant investments in infrastructure. The impact will be strongest in the market segment for alternative drive technologies and in transportation infrastructure and traffic management. One driver of digitalization is easier customer access, which, above all, will translate into the individuality and simplicity of new and combined modes of transportation.

Digitalization will swell the market segment for alternative drive technologies by 1.5 billion euros (5 percent) to 34 billion euros in 2025. This development will increasingly be fueled by the use of electric drive systems, but also by forceful growth in the technology line for car sharing, where digitalization is expected to boost the market volume by 65 percent in 2025. The key drivers here are connectivity and digital customer access. Environmentally friendly alternative drive technologies can, for example, be deployed more easily in car sharing contexts as users/customers incur no heavy and acute investment costs. Even in private transportation, there is a growing willingness to turn to new drive technologies.

In the market segment for transportation infrastructure and traffic control, digitalization will add 1.6 billion euros (4 percent) to the market volume. Digitalization will thus be instrumental in driving expansion of the technology lines for cycle paths, public transport and filling station infrastructure for alternative drive systems.

The lead market for waste management and recycling
In volume terms, the lead market for waste management and recycling accounts for a comparatively small share of the overall green tech industry and is projected to reach 32 billion euros in 2025. Annual market growth will be 5.7 percent in the period from 2016 through 2025. The effects of digitalization should increase the volume of this lead market by 1.8 billion euros (5.6 percent) in 2025.

Digitalization is boosting this lead market by joining up the individual steps in recycling and making use of data. This is having a particularly profound impact on the market segments for material recovery and waste collection, transportation and separation.

The 6.9 billion euros volume of the market segment for material recovery in 2025 can be increased by 0.8 billion euros (11 percent) by the additional effects of digitalization. This considerable gain in percentage terms can be attributed to the way in which digitalization raises recycling rates. Material recovery is expanding significantly, and the shift in the breakdown of feedstock and mechanical recycling is benefiting the environment. For example, the greater use of reusable prefabricated elements in construction and the increasing use of electronic components are both contributing to a larger market volume as a result of digitalization. The driver is the use of digital data to label products and buildings (or building parts), as the precise identification of the substances used in products and materials promotes efficiency in waste management and recycling. Digitalization will also influence the volume of the market segment for waste collection, transportation and separation, adding 1 billion euros (5 percent) to the 20.9 billion euros figure projected for 2015. Especially in waste separation, automation is expected to lead to substantial market growth.

The lead market for sustainable water management
Between 2016 and 2025, this lead market is set to grow by 50 billion euros to a total volume of 78 billion euros, which works out at annual growth of 10 percent across the whole of this period. If the effects of digitalization are included, an extra 0.8 billion euros (1.1 percent) can be added to this figure in 2025.

The pivotal issues in the lead market for sustainable water management are digital data and the advance of automation, which are sustainably improving the efficiency of both water usage and water production and treatment.

The small scale of the percentage increase in market volume is a clear indication that digitalization has little influence on the trend in sales in this lead market. Water pipes in particular have a service life spanning several decades. Digital sensors are seldom used, and structural alterations to optimize the networks that supply drinking and process water tend to be the exception. In most industries, cooling and process water cycles have already been optimized to a considerable extent in the past. This explains why the strongest growth is in the market segment for efficiency gains in water usage. Since Germany also does not have large-scale irrigation systems in agriculture, digitalization will drive a 4 percent increase in the market volume in this segment, from 12.7 billion euros to 13.2 billion euros. Given the global situation with regard to the supply of drinking water and agricultural irrigation, however, this market is believed to harbor huge potential for exports. Spending on geodata and weather data analytics with a view to water efficiency technologies and climate-adapted infrastructure (flood protection) definitely looks like a worthwhile investment.

Ecological potential of digitalization

Environmental technology and resource efficiency inherently contain significant potential to ease the burden on the environment and protect environmental goods. Economic growth in this industry therefore also leads to positive ecological effects, including both the potential and actual environmental relief achieved by using a product, process or service. Digitalization will amplify these ecological effects.

This section examines the effects on the climate realized by saving energy and material on the basis of the equivalent carbon dioxide (CO_2e) saved.[58] CO_2e includes emissions of all gases of relevance to the environment, taking due account of their respective warming potential. Calculation of the CO_2e emissions resulting from the generation of electricity, for example, also makes provision for upstream and downstream process chains (the construction and operation of power plants, the

58 CO_2 equivalents are the parameter used to measure a substance's global warming potential, or GWP. The GWP is the impact of a certain quantity of greenhouse gas on the global warming effect. It describes the mean warming effect over a defined period. The global warming potential of each greenhouse gas is expressed in terms of carbon dioxide (CO_2).

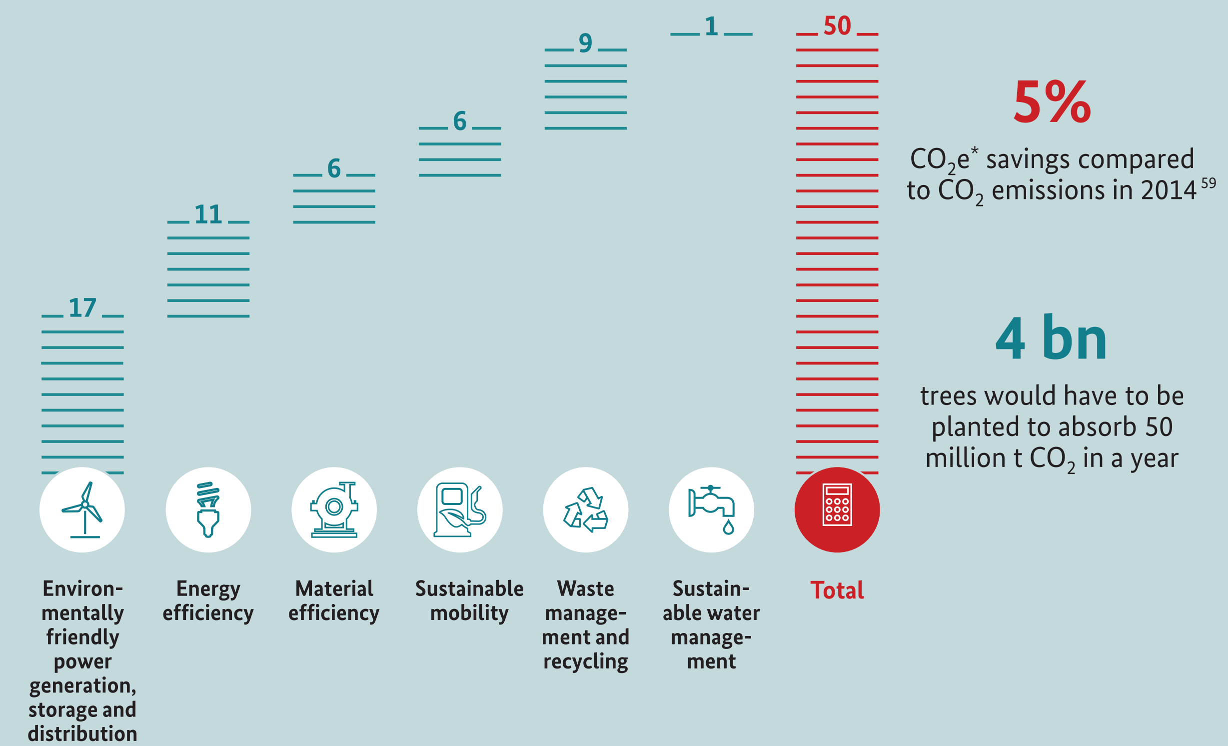
production, treatment and transportation of fuel etc.). Digitalization is having an impact on climate action, but also on other environmental goods such as air, water, soil, biodiversity, countryside and noise. Examples are presented in our discussion of the individual lead markets.

The scope of environmental relief potential in the environmental technology and resource efficiency industry and its individual lead markets varies – as does the pace of development – even in conventional development forecasts (i.e. those that do not yet include the added effects of digitalization). In the course of the green transformation and in the green economy, non-digital solutions tool help ease the burden on the environment. Environmental relief potential is expected to grow in the lead markets for environmentally power generation, storage and distribution, sustainable mobility, waste management and recycling, and sustainable water management in the years from 2015 through 2025. By contrast, environmental relief potential in the lead markets for energy efficiency and material efficiency (excluding digitalization) is expected to decrease in the same period – sharply, in some cases.

Only with digitalization can further environmental relief potential be actively tapped across all the lead markets. Why? Because digitalization enhances the relief potential that is already forecast without digitalization. In the six lead markets, digitalization is expected to generate extra environmental relief potential of 50 million tonnes of CO_2e in 2025. That equates to a 5 percent reduction in total German CO_2e emissions relative to 2014 due to the effects of digitalization alone.

Digitalization will make the biggest contribution to extra environmental relief – 17 million tonnes of CO_2e in 2025 – in the lead market for environmentally friendly power generation, storage and distribution. Significant additional relief will also be generated in the lead market for energy efficiency, where 11 million tonnes of CO_2e will be saved. The lead

Figure 86: Additional CO_2e savings (in millions of tonnes) through digitalization in the individual lead markets in Germany in 2025



* Carbon dioxide equivalent

Source: Roland Berger (2017)

59 See Umweltbundesamt (2017e).

markets for material efficiency and sustainable mobility are each expected to see extra environmental relief potential of around 6 million tonnes of CO_2e due to digitalization. In the lead market for waste management and recycling, the corresponding figure will be 9 million tonnes of CO_2e. Less pronounced additional relief potential of 1 million tonnes of CO_2e will be realized in the market for sustainable water management.

There are three ways to save CO_2e: Taking energy and material consumption as the point of departure, processes, services and products can either be avoided, substituted or made more effective. Avoidance has the biggest impact on environmental relief potential. Since most resources and materials are not extracted or produced in Germany, the resultant environmental relief potential materializes primarily on a global level. Substitution has a less marked effect: If conventional building materials are replaced by renewable building materials, there is no reduction in material consumption, but the products used are more ecofriendly, which has a positive impact on environmental relief potential. The least effect in terms of increasing environmental relief potential is realized by improving process efficiency: Since there is no fundamental change to the processes involved, most still retain a minimum level of emissions. There is also the danger that the overall carbon footprint may be adversely affected if devices are replaced by more efficient successor models. The production of even these efficient devices itself creates emissions, which must in turn be factored into the big ecological picture. One example is when old air-conditioning systems are replaced by new ones.

The sections that follow analyze and evaluate the environmental relief potential in the individual lead markets.

The lead market for environmentally friendly power generation, storage and distribution
In the lead market for environmentally friendly power generation, storage and distribution, the effects of digitalization will create additional environmental relief potential of 17 million tonnes of CO_2e in 2025. Overall, the potential of digitalization to enhance environmental relief is thus rated very highly in this lead market. Digitalization makes renewable energy more cost-effective by joining up the generation, storage and distribution of (mostly electric) power. Distributed power generation can develop its full potential when it is plugged into smart grids, all of which makes it a more attractive proposition for expansion. This in turn reduces fossil-fuel-based power generation, prompting a sizeable decline in CO_2e emissions. Given that a large volume of power that can be generated in this way, the corresponding environmental relief potential is considerable. And since low-carbon nuclear energy is to be discontinued by 2022, a power generation gap will emerge that must be filled by renewable energy.

Above and beyond climate change mitigation, other environmental goods too will benefit from the relief provided by digitalization in this lead market. Smart power grids can reduce demand for high-voltage power lines whose construction regularly damages the environment and sparks off public protests. Distributed connectivity on the basis of smart micro-grids in the distribution grids and the intelligently fragmented storage of energy will ease the load on the transmission networks that digitalization has already optimized to a great extent. Woodlands and countryside will be preserved as a result.

The lead market for energy efficiency
In the lead market for energy efficiency, digitalization is needed to tap fresh potential and breathe new life into conventional energy productivity, which has been stagnating since 2006. The effects of digitalization will generate additional environmental relief potential of around 11 million tonnes of CO_2e in 2025. Here again, the overall additional relief potential afforded by digitalization in this lead market is rated highly.

Digital connectivity across devices and components enables inefficient stand-alone solutions – in air-conditioning systems, for instance – to be avoided. Instead, efficient energy consumption management systems can be introduced in industrial, commercial and household contexts. Energy-efficient production processes bring relief in connected production plants, too, as digitalization generally lessens demand for energy. As a result, both the emissions generated by burning fossil fuels and the impact of their extraction on countryside and waterways can be attenuated. Unlike in the lead market for environmentally friendly power generation, storage and distribution, however, that does not necessarily lead to shifts in the share of gross electricity production accounted for by the different energy sources.

The lead market for material efficiency
In the lead market for material efficiency, the effects of digitalization could create additional environmental relief potential of around 6 million tonnes of CO_2e in 2025. On the whole, the extra relief potential afforded by digitalization is thus regarded as moderate in this lead market.

Digitalization affects this lead market in two ways: through greater transparency and through new production processes. On the one hand, the use of digital data allows information to be utilized more readily, making it easier to track and optimize material inputs in the production process, for example. On the other hand, material efficiency can be increased significantly by means of new products and production processes – one example being adaptive manufacturing.

By no means least, the efficient use of resources is also gaining in importance in ICT products. Resources are finite, and valuable minerals are extracted under difficult environmental and working conditions. By making product information more transparent, digitalization is increasingly fostering an awareness of environmental issues among the wider population. Construction materials are now being selected with a view to better indoor climatic conditions and greater well-being for users. Natural, renewable resources are being used, and it is becoming possible to reduce traditional materials. Automated production facilities and end-to-end simulation mean that material-saving processes are only now beginning to realize their full digital potential. Additive manufacturing is an example of this kind of digitally controlled process: It is replacing solid structures with finer, optimized structures that are inspired by nature and thus save on materials.

The lead market for sustainable mobility
In 2025, digitalization should generate additional environmental relief potential of 6 million tonnes of CO_2e – regarded as a moderate gain overall – in the lead market for sustainable mobility.

Digitalization's impact on environmental relief potential in this lead market stems primarily from the fact that traveling fewer kilometers leads to lower CO_2 emissions. Convenient digital tools make offerings such as car sharing more attractive to users and thus promote the wider use of environmentally friendly drive systems. They also add to the attraction and convenience of local and long-distance public transportation, boosting passenger figures and thereby curbing individual motorized traffic volumes. At the same time, digitalization and digital devices are increasingly undermining the automobile's role as a status symbol in Germany. More and more users now see cars as a commodity: It is merely one of many options to get around. A smart infrastructure stakes out the framework for this development. Optimized route planning and traffic flow analysis not only saves time, but also reduces carbon emissions by shortening the distances traveled and the duration of traffic congestion. On top of this potential to protect the climate, relief is also provided for the environmental goods noise, countryside and the air. People benefit directly from this relief (unlike in the case of lower CO_2 emissions, whose impact is felt only indirectly and after a time lag).

The lead market for waste management and recycling
The effects of digitalization will add environmental relief potential totaling 9 million tonnes of CO_2e to the lead market for waste management and recycling in 2025. The relief potential effected by digitalization is thus expected to be moderate.

The principal digital drivers of environmental relief potential in the lead market for waste management and recycling are automation and data analytics, both of which lead to less waste and more mechanical recycling. The recycling rate can be increased considerably in all areas of consumption and production, as digital planning and labeling support reuse. Digitalization creates all kinds of opportunities to develop closed product cycles. Further reducing the mining of raw materials protects the countryside, but also lowers the CO_2 emissions given off during resource extraction. Shared economy and cradle-to-cradle approaches are prompting the rethinking of waste management and recycling as a whole. Even landfills are being tapped as a source of materials. Automating waste separation raises efficiency and, above all, the intrinsic value of recovery. This is one possible way to replace pre-crushing with smart, selective processes.

The lead market for sustainable water management
In the lead market for sustainable water management, the effects of digitalization can yield additional environmental relief potential of 1 million tonnes of CO_2e in 2025. Overall, the potential of digitalization to create added relief potential in this lead market is seen as low. In sustainable water management, the ecological potential of digitalization is rooted mainly in smart sensors and process optimization. By connecting irrigation systems to weather and climate data, water can be used more efficiently in agriculture. Unlike other countries where farming is more widespread, though, industrial production accounts for the bulk of water use in Germany – and thus also harbors the greatest potential to protect water as an environmental good and maintain the purity of the country's waterways. Here, digitalization lays the foundation for smart water management that interlinks systems, components and software to generate data about the water cycle. This data can then be used to raise the level of automa-

tion, shorten response times and process information in real time. Losses through the pipeline system can be checked very precisely and the findings relayed to water feeds. Wastewater cleaning and treatment can be intelligently integrated in the water cycle to lower demand for fresh water. The overall effect is not only to protect water as an environmental good, but also to help preserve biodiversity in water. At the same time, smart water management systems can reduce energy consumption, as intelligent controls scale back demand for water treatment. Examples of digitalization in this lead market include zero liquid discharge and hydraulic plant simulation.

7

Transformation processes in green tech and in traditional industries

The digital transformation is facilitating ecological modernization

Green tech players' products, processes and services play a crucial role in mastering ecological challenges. As a cross-sector industry, environmental technology and resource efficiency also promotes the green transformation in other branches of industry. Integrated approaches and system solutions in particular look highly promising, with digitalization playing a pivotal role in both. Digitalization creates opportunities to develop and improve products, processes and business models – provided green tech companies stand up to the challenges presented by digital transformation.

At a glance

For many green tech players, the digital transformation is still in its very early days. Companies in the environmental technology and resource efficiency industry must face up to five main challenges: securing access to customers; becoming more flexible and agile; developing digital skills and making better use of new forms of collaboration; adjusting their finances; and developing a digital enterprise model.

In its capacity as a cross-sector industry, environmental technology and resource efficiency promotes the green transformation in other branches of industry too, injecting powerful stimulus for the ecological modernization of the economy. Since 2007, green tech has increasingly raised its share of Germany's gross domestic product (GDP), of which it is expected to account for 19 percent by 2025.

Digitalization can support and accelerate the green transformation by putting in place the technical conditions required for many steps to protect the environment and mitigate climate change. By establishing data networks, smart system solutions can realize far greater energy savings than non-automated processes. At the same time, digitalization facilitates the economies of scale that can make sustainable products and services cost-effective and pave the way to their wider use. Digitalization also enables information to be bundled and visualized in clear, intuitive forms. All these insights can be harnessed to further the development of ecofriendly technologies and services.

The term "green economy" denotes an innovative economy that limits ecological risks and seizes economic opportunities. The process of developing from the status quo to a green economy is referred to as the "green transformation". Transformation literally means to change the shape or form of something. In other words, it refers to profound structural alterations rather than superficial adjustments. The concept of transformation can be mapped onto the corporate level, too. Companies play a central role in moving us toward the goal of a low-carbon, resource-efficient green economy. And in order to do so, they themselves must set out along the path toward transformation. In this context, transformation means consciously deciding to bring about focused and fundamental change. That must begin in the key dimensions of corporate activity: management and employee behavior, structures and processes, and positioning on the market.

This chapter explores different aspects of the transformation. It begins by exploring the transformation process that digitalization is forcing on green tech companies. Drawing on case studies, it then examines how companies in traditional industries are mastering the challenge of the green transformation.

The digital transformation of the green tech industry

For German companies in the environmental technology and resource efficiency industry, digitalization is opening up many and varied opportunities to improve their competitive position by injecting innovation into their products and internal processes. Conversely, companies that ignore the megatrend toward digitalization run the risk of seeing digital-savvy rivals steal their market share. There will be winners and losers from the digital transformation – which is why businesses must tackle it proactively. A first step is to determine one's level of "digital readiness": To what extent is the company ready for the digital transformation?

The point of departure for companies in the green tech lead markets is determined on the basis of four criteria: start-up activity, the use of digital technologies, the existence of digital systems and the pace of innovation. Based on a qualitative assessment of these four criteria, the degree of digital readiness in each lead market was calculated on a scale from 0 to 100 percent (see Figure 87).

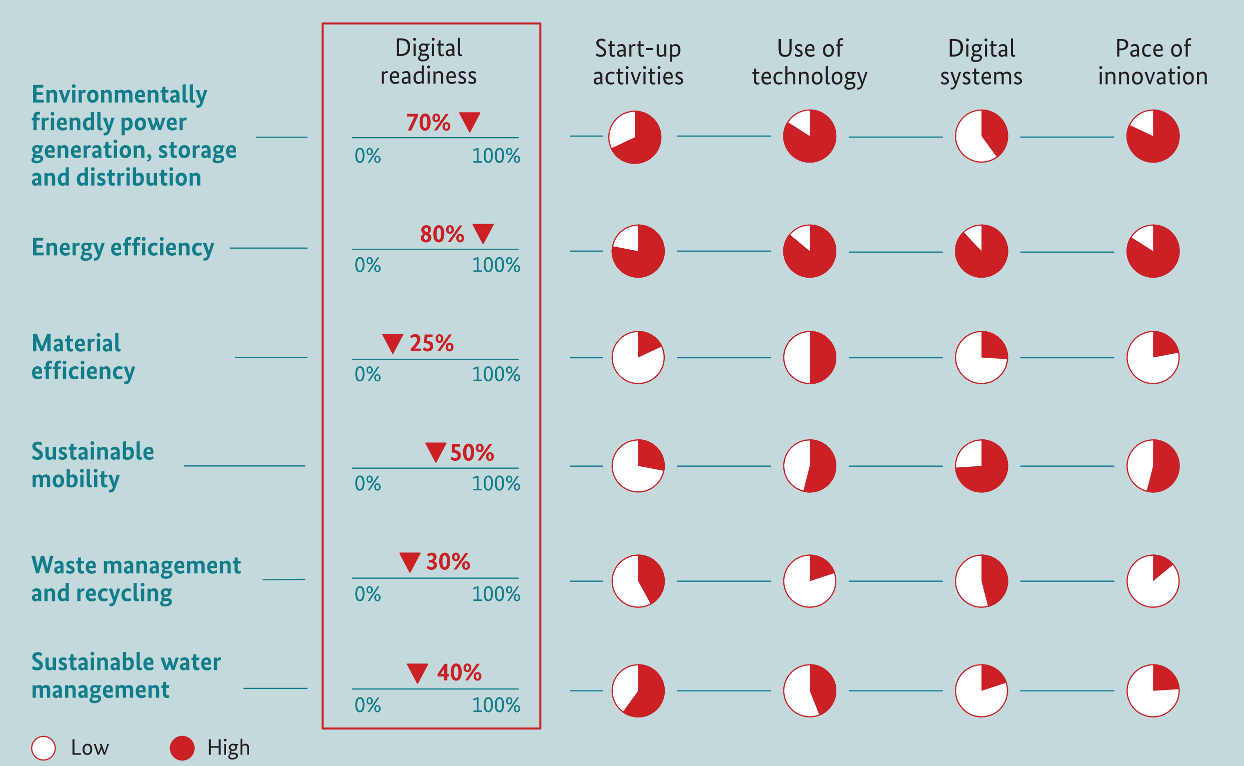
Of all the green tech lead markets, energy efficiency leads in terms of digital readiness with the highest score of 80 percent. A large number of start-ups and a broad spectrum of innovative digital efficiency services are the main reason for this lead market's strong digital starting position. Another factor is the substantial availability of digital systems even now, which suggests that the technological environment is already well developed. Innovative technologies and new business models can thus be applied more quickly on the market.

Another good overall digital readiness score – of 70 percent – is recorded by companies in the lead market for environmentally friendly power generation, storage and distribution. Digital solutions from numerous start-ups relating to the control and integration of renewable energy and storage technologies show that, in some market segments, digital technologies are already in use today and are successfully placed on the market. In contrast, the digital point of departure in the lead market for waste management and recycling is much weaker, with a digital readiness score of 30 percent.

Only a few companies in the waste management industry are already using digital technology or currently conducting pilot projects – in dynamic waste collection and the digital labeling of consumer goods, for example. That in turn inhibits the speed of innovation and, hence, the number of applications for patents in this field.

In the lead market for material efficiency, the digital transformation is still in its early days. An overall digital readiness score of 25 percent makes this point abundantly clear. Given the complexity of the issues involved and the long-term nature of development processes in what is mostly a context of industrial production, start-up activity is still very rare. Nor is much happening in terms of innovation in the area of digital services – witness the small number of patent applications relating to digital innovations in this lead market. Even in the context of Industry 4.0, the topic of material efficiency is only slowly being recognized as a relevant issue.

Figure 87: Digital readiness in the six lead markets for environmental technology and resource efficiency in Germany; assessment criteria used



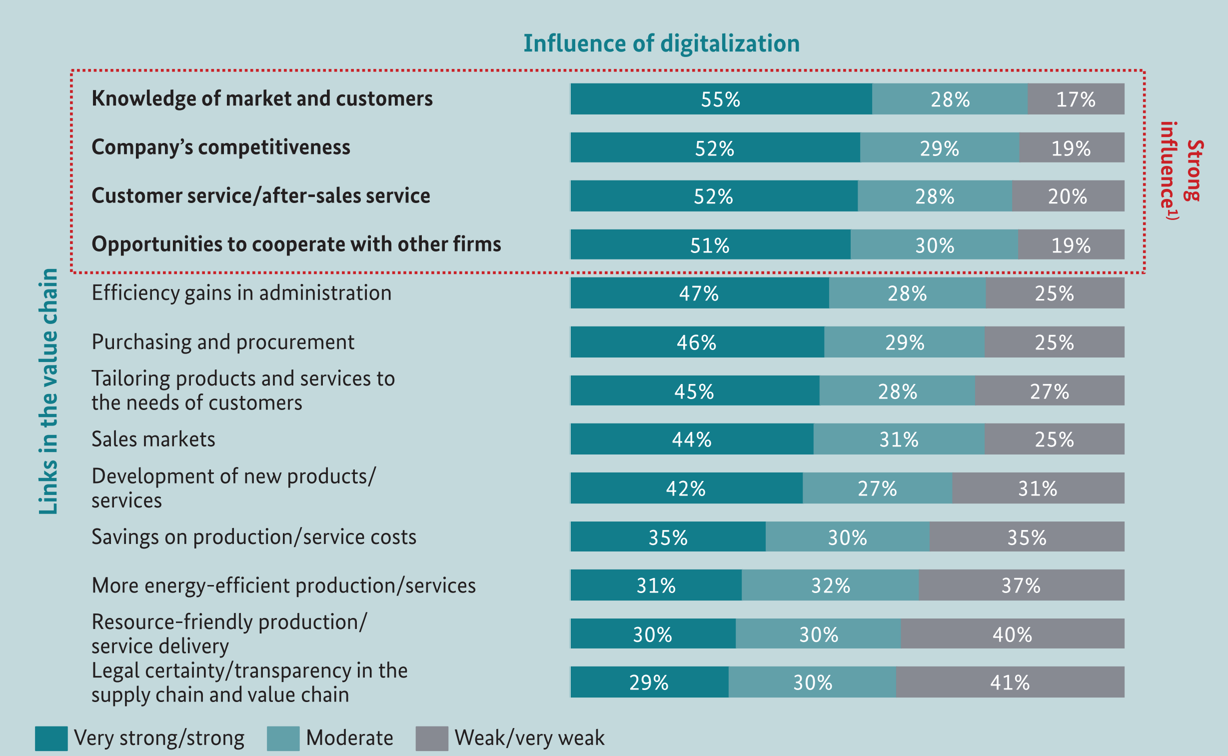
Source: German Patent and Trademark Office, company websites, Borderstep Green Economy start-up monitor, Roland Berger (2017)

Companies' own assessment of digitalization

Discrepancies between self-perception and how others see things are nothing unusual. When the companies were surveyed, one important aspect was therefore how green tech players themselves rate digitalization. One question looked at how digitalization influences different links in the value chain. Essentially, companies expect digitalization to give them a sharper competitive edge, a better knowledge of markets and customers, and new possibilities for service and co-operation. Especially in relation to the development of energy-efficient products, processes and services that use less natural resources, the respondent companies did not see much of an influence from digitalization (see Figure 88).

The green tech players were questioned about how they rate the challenges of digitalization. Specifically, they were asked to cite the extent to which they agreed with the proposed statements (see Figure 89). Most respondent companies clearly see data security and the growing pressure to innovate as their biggest challenges. The majority of firms do not perceive digitalization as a threat to their own business model.

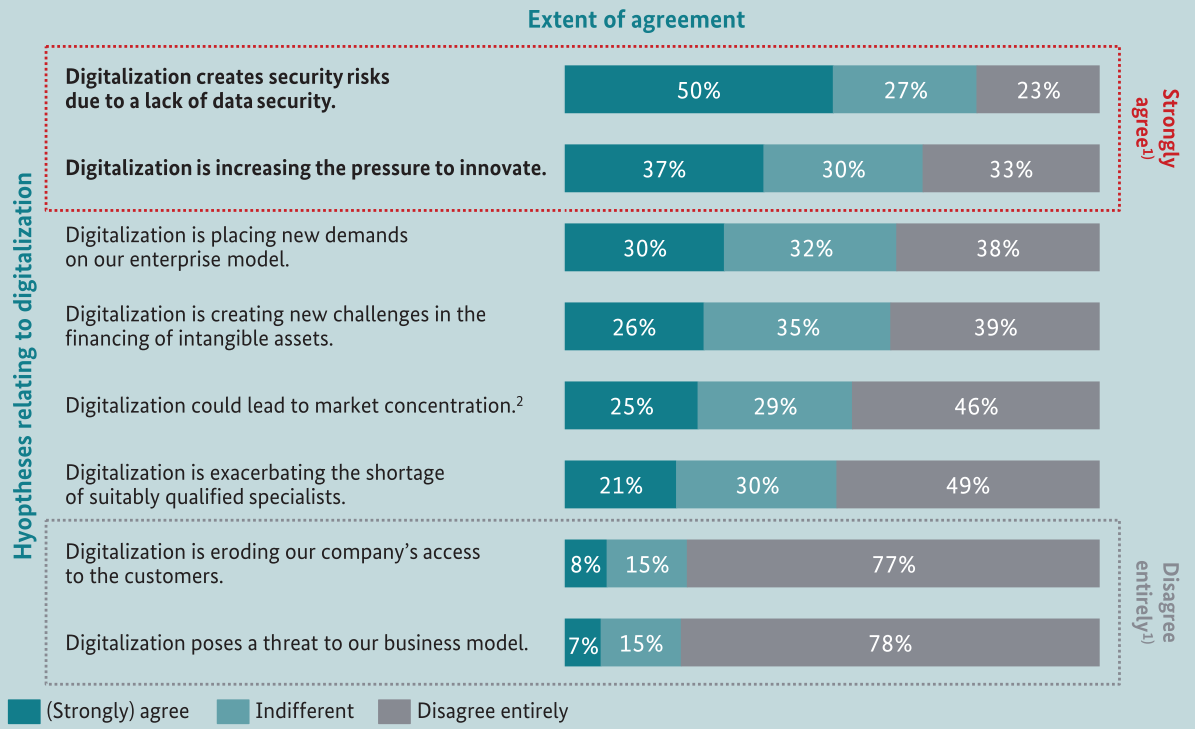
Figure 88: Influence of digitalization on individual links in the value chain (percentage of mentions)



1) Influence is regarded as "strong" if "very strong/strong" scores over 50%.

Source: Company survey (941 responses), Roland Berger (2017)

Figure 89: Impact of digitalization from the perspective of green tech companies (percentage of mentions)



1) Agreement is regarded as "strong" if "(Strongly) agree" scores over 35%; no agreement if "Disagree entirely" scores over 65%
2) When a market experiences concentration, revenue shares are spread across an ever smaller number of companies.

Source: Company survey (888 responses), Roland Berger (2017)

The five challenges posed by the digital transformation

For many environmental technology and resource efficiency companies, the digital transformation is in its very early days. To seize the opportunities that are opening up and avoid being shunted into an analogue dead end, players in Germany's green tech industry must face up to five main challenges (see Figure 90).

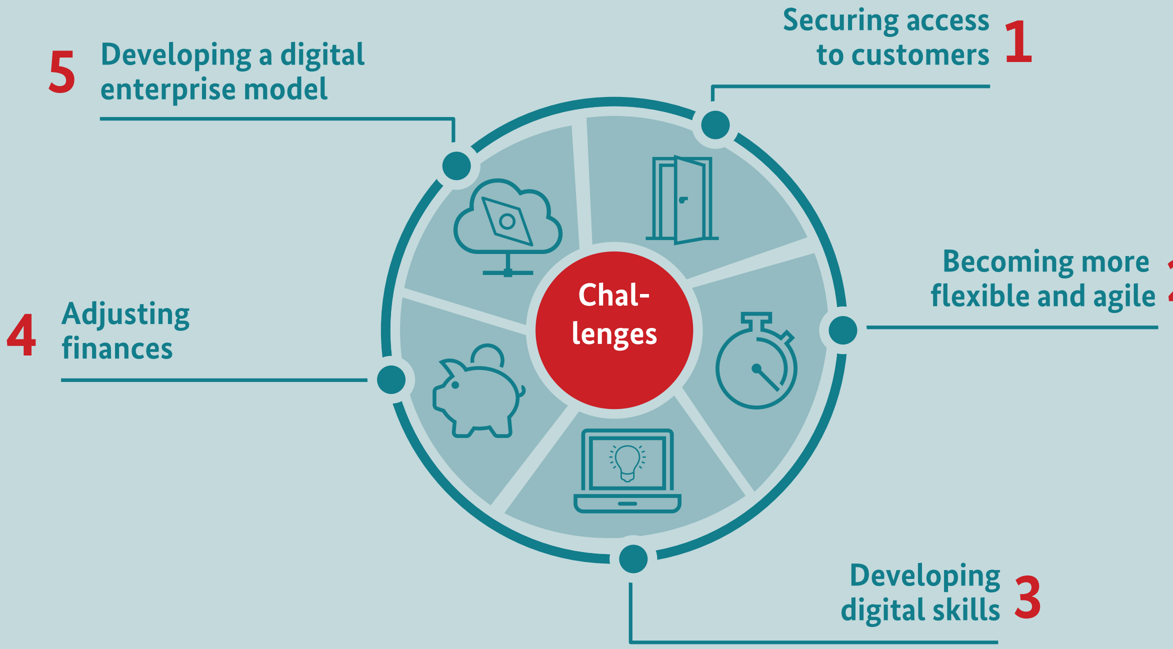
Germany's small and medium-sized enterprises (SMEs) are already familiar with some of these concerns. The shortage of suitably qualified specialists, the need to fund growth strategies and a clear strategic orientation are challenges that all pre-date digitalization. That said, the digital transformation has increased the pressure of time: Players in Germany's green tech industry, many of whom are medium-sized firms, must rise to these challenges quickly if they want to end up among the digital winners.

Challenge #1: Securing access to customers
The digital transformation is changing sales channels. Traditional retail is losing its clout even as online sales continually gain in importance. Platforms – including comparison and rating portals, sharing platforms, app stores and online marketplaces – have established themselves as a core element of the digital economy. These platforms give companies direct access to customers, which is a tremendous opportunity for the providers of products and services: Dialogue with users cements customer loyalty and generates useful information on how to improve the seller's portfolio.

Yet platforms also create the risk that intermediaries may occupy the interface between producer and consumer. By consequence, platform operators can then dictate their own rules of the (selling) game to the providers of products and services. Since platforms add to supply-side transparency, this often narrows providers' margins and intensifies price wars.

Established players should seek to counteract these tendencies by launching their own sales platforms and selectively integrating value-added partners. In doing so, they add value for their customers – for example by marketing system solutions. In such constellations,

Figure 90: Digitalization in the environmental technology and resource efficiency industry – The five biggest challenges facing German green tech companies



Source: Roland Berger (2017)

manufacturers, installation technicians and operators from different companies work together and place a point of single contact or a single platform at the customer's disposal. Customers can still buy all products straight from the manufacturer, but it becomes easier to customize them, add extra services and inquire about specific system solutions. New business models based on updates and upgrades open up additional sources of revenue and nurture lasting customer loyalty. For environmental technology and resource efficiency players in particular, this has the benefit of letting them integrate their capabilities and innovative strengths more deeply in the sales process and turning this into a competitive advantage.

Challenge #2: Becoming more flexible and agile

New technologies and business models are flooding the market ever faster as digitalization accelerates innovation cycles. The traditional research and development processes still in place in many companies are often unable to keep up with this pace: Most such processes were designed to advance evolutionary developments rather than spawn disruptive innovations. This is where agile approaches can prove highly promising. Characteristic attributes of agile strategies include soliciting customer feedback at an early stage of the innovation process, pursuing iterative product development ("rapid prototyping") and applying the principles of "testing and learning" and "learning from failure". Although these basic principles of agility shape the culture of start-ups in particular, incumbent players too can benefit from them. The latter's vast experience of production gives them a speed advantage in production.

Digitalization gives green tech companies the chance to boost their revenue and become more effective and efficient. Digital solutions facilitate simple, fast decisions and processes within the organization. To realize this effect, businesses must be willing to call legacy structures into question and move on from traditional ways of thinking to a digital mindset. The process of digitalization is supported not only by corporate IT departments, but also by digital experts in the project groups. In the context of digitalization, it is not only permitted but, in some cases, indispensable to question one's own business model. Carving out separate project groups, each with their own budget, has proven a promising way to develop disruptive innovations. These teams operate like start-ups within the organization, but their creativity is not inhibited by the constraints of day-to-day business.

Challenge #3: Developing digital skills

Businesses that are keen to succeed in the digital economy obviously need highly qualified specialists. But they also need strategic skills in the key areas of digitalization. Behind all the talk of Industry 4.0, big data, apps and wearables, we find business models, products and services. And to navigate safely through uncharted digital territory, companies need to understand that digitalization affects every link in the value chain, as well as the organization's management culture. Company leaders must make decision processes more transparent. They must communicate them and ensure that the skills available within their organization can be used to the full. The consequences of digitalization do not stop at a company's established processes and structures. New digital solutions demand new forms of cooperation within the organization – cooperation that must not be allowed to grind to a halt at departmental boundaries. Cooperation in interdisciplinary teams is growing ever more important, necessitating a collaborative, solution-oriented work environment in which employees have free access to data and where communication is backed by digital support. Cloud solutions put the conditions in place for this to happen.

If firms are to shape the digital transformation successfully, they need digital skills at both the strategic and operational levels. Digital literacy is not just a matter for the IT department, because digitalization transcends both functional and hierarchic boundaries. Digitalization will work if people across all parts of the company contribute or cultivate digital literacy. A combination of analytical skills and creativity in particular encourages innovation. This profile is perhaps best matched by graduates of disciplines such as digital engineering and entrepreneurship, which dovetail traditional sciences with the digital world.

Challenge #4: Adjusting finances

Digitalization changes financing needs at every point in the value chain. Above all, it alters the value of tangible and intangible assets. Conventional capital investment targets only production resources intended for long-term use, such as machinery, buildings and land. And in the past, this kind of tangible asset was a key parameter in assessing a company's value or creditworthiness. In the digital economy, intangible assets such as new operating systems, patents, employees' knowledge, digital strategies and data have moved center-stage. Putting a value on intangible assets is a complex task, however, and many lending banks and financial institutions still find it hard to assess new business models and the risks to which they are exposed. In many cases, established forms of credit ratings are not appropriate in the context of digital business models.

Against this financial backdrop, green tech companies need to find individual solutions. The basic options include funding in the form of long-term credit arrangements, boosting the equity ratio and tapping alternative sources of finance such as crowd-investing. Where innovative business models are launched, it is also possible to share financial risks by cooperating with suppliers and/or competitors. Funding options such as renting, leasing and pay-per-use arrangements are likewise gaining in significance, allowing even specialized web-based solutions for operating procedures and big data analytics to be integrated at low cost. The growing number of open source products that provide free alternatives to both traditional office tools and specialized data analytics software are another ideal solution.

Challenge #5: Developing a digital enterprise model

Digitalization always affects the entire organization – at every link in the value chain. It follows that the recommendations cited above cannot be seen in isolation: They can only be implemented in the context of an end-to-end digitalization strategy. Developing this kind of digital enterprise model should therefore figure high on the agenda of every management team.

In reality, however, few companies yet have this kind of digital enterprise model. Routine problems and pressures frequently keep management too busy to deal with strategic matters. Companies also have a hard time recognizing – and responding appropriately to – the anticipated changes in our living and working environment. There is still a widespread belief that digitalization "only" concerns sales operations or is confined solely to consumer goods. Accordingly, many businesses adopt only a half-hearted approach to the digital transformation, instead of grafting digitalization into every area of the company. In many cases, attempts to adjust the IT infrastructure are all that happens.

Like firms in other industries, green tech companies should be tackling the subject of digitalization proactively. One first step is to be aware of the keys to digitalization and understand their impact. Managers need to analyze how digital technologies will affect their industry in general and their company in particular. Above all, they must analyze which disruptive trends triggered by digitalization could pose a threat to their own business model and competitive position. Merely kicking the tires of risk scenarios is not enough, however. It is also vital to develop and adjust opportunities,

processes, products and business models in line with the conditions that prevail in the digital economy. That has to begin by honestly taking stock: Which products, customers and regions are affected by the digital transformation? Adopting a clear position in response to these questions can lead to the successful development of a digital enterprise model with a clear vision and an implementation roadmap. Given the frantic pace of the Internet economy, a digital enterprise model can never be a target scenario that is cast in stone for the medium to long term. It must be constantly reevaluated and readjusted, because responding rapidly to changes in the market environment is a key success factor in any digitalization strategy.

The green transformation in traditional industries

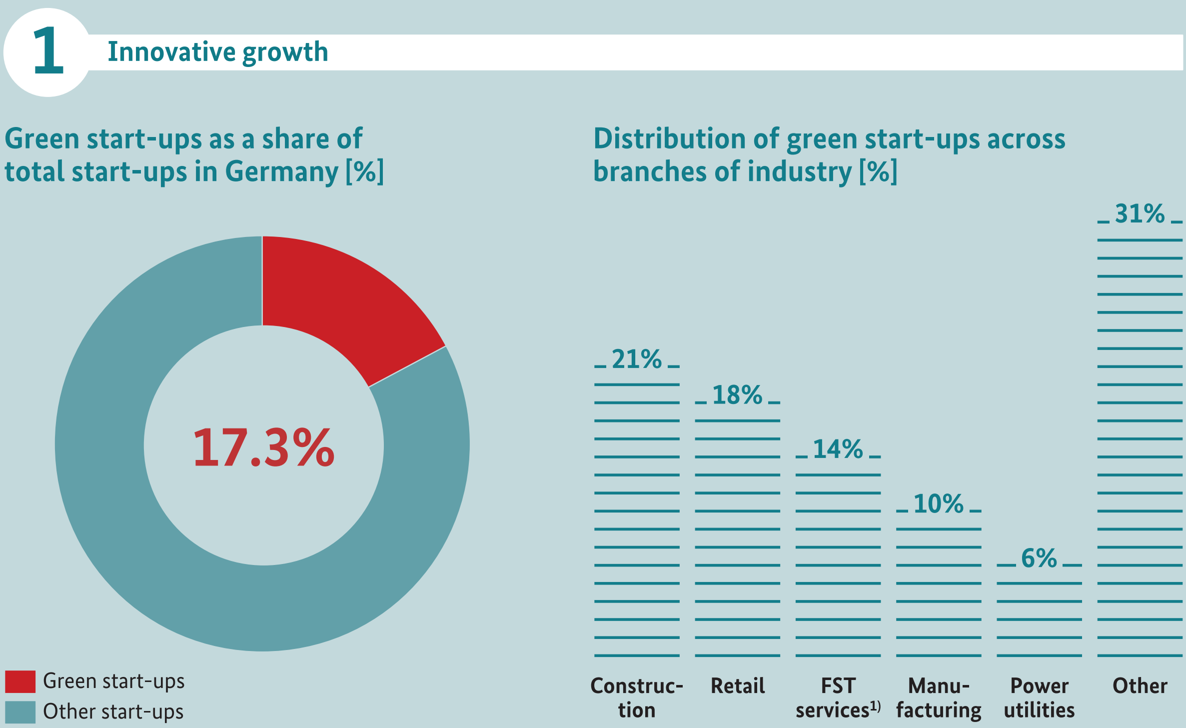
The green economy can be defined as a system of economic activity characterized by innovative, ecological and inclusive growth. The three attributes “innovative”, “ecological” and “inclusive” refer to different dimensions of activity. “Innovative growth” covers education, knowledge transfer and research and development (R&D). Subjects such as the teaching and research activities of universities in disciplines of relevance to the environment, the number and scope of government funding programs for green research and development projects and the number of patent applications with links to environmental technology and resource efficiency fall under this rubric.

Within the “innovative growth” dimension, the R&D activities of higher education establishments and companies in particular are instrumental in mitigating climate change and protecting the environment. These players develop technologies and completely new products and processes, which in turn lay the foundation for innovative, sustainable growth.

Founding green companies with creative approaches can speed up the resolution of environmental problems. Most small and medium-sized enterprises are not hampered by time-consuming internal coordination processes: They can simply go ahead – on their own or together with customers – and develop innovative, disruptive technologies and processes. Successful technologies can quickly be absorbed and further disseminated by the wider market.

17 percent of all German start-ups operate in green disciplines, positioning Germany as one of Europe’s front-runners. Taken together, the construction and retail industries account for 39 percent of all “green” German start-ups (see Figure 91).

Figure 91: Green start-ups as a percentage of all new business launches in Germany and their distribution across individual industries (2014) [1]



1) Freelance, scientific and technical services

Source: Borderstep Institute for Innovation and Sustainability (2016), Roland Berger (2017)

1 See Fichter, Klaus / Weiß, Ralf (2016).

The "ecological growth" dimension relates to factors that burden the environment and have a material influence on people's quality of life. These include improving resource efficiency, reducing greenhouse gas emissions and preserving biodiversity.

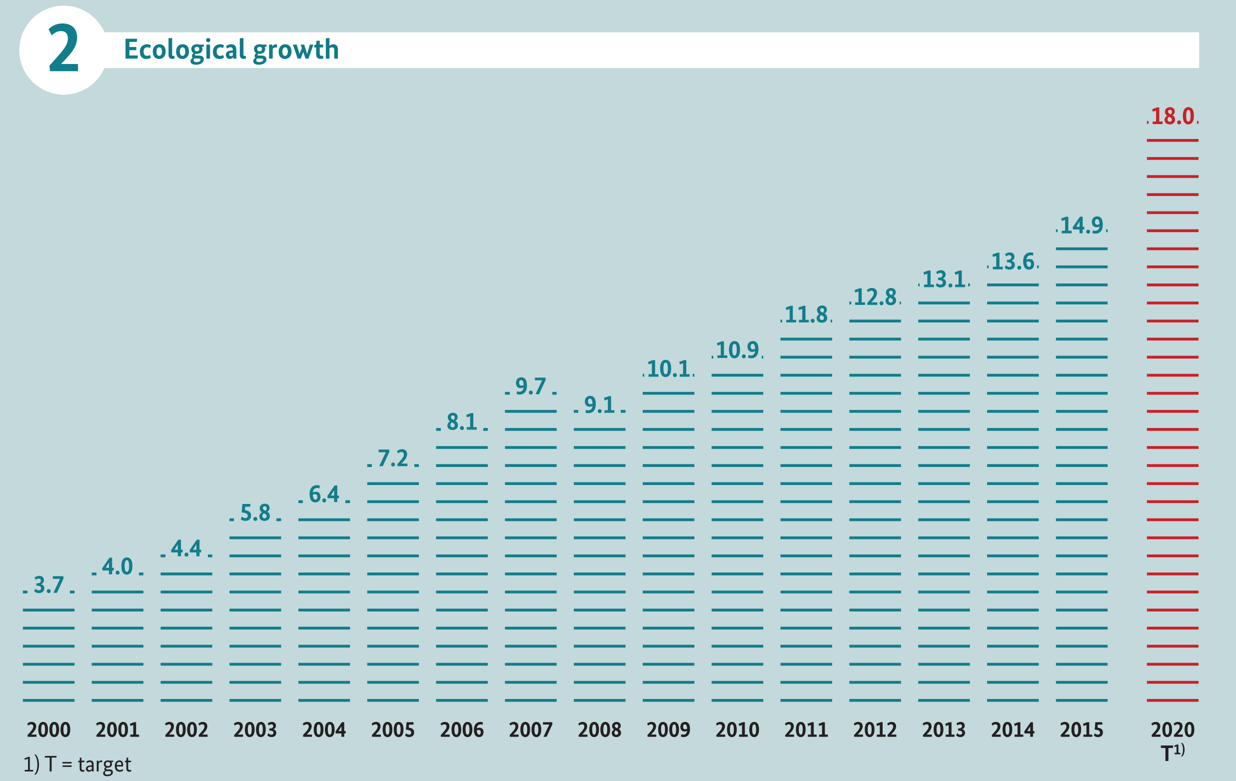
Ecological growth can make a major contribution to climate and environmental protection. improving resource efficiency in production and services in particular. The ongoing optimization of processes curbs the consumption of materials and energy. In recent years, resource efficiency has become especially important to the corporate sector because, on top of its impact on the environment, it also helps cut costs. One powerful way to improve energy efficiency is to make use of waste heat, for example. Using and processing waste and by-products improves material efficiency and thus eases the burden on the environment. To cite just one example: Exhaust emissions given off by blast furnace processes can be channeled into the chemical industry for use as educts in the synthesis of polymers.

A good example of progress in ecological growth is the continuing expansion of renewable energy. Figure 92 shows that renewable energy has sharply increased its share of gross final energy consumption since 2000. By 2020, renewable sources will probably account for one fifth of gross final energy consumption.

The "inclusive growth" dimension refers to both popular participation in the green economy and the practice of anchoring green economic principles in politics, the economy and society.

One pointer to an ever more sustainable economic orientation is the contribution made by environmental technology and resource efficiency to economic output. As visualized in Figure 93, the green tech industry has increased its share of German gross domestic product (GDP) continually since 2007, reaching 15 percent in 2015. The expectation is that, by 2025, environmental technology and resource efficiency will make up 19 percent of Germany's GDP.

Figure 92: Renewable energy as a share of gross final energy consumption in Germany from 2000 through 2020 (percent)



1) T = target

Source: Federal Environment Agency (2016), Roland Berger (2017)

Figure 93: Growth in environmental technology and resource efficiency's share of nominal gross domestic product in Germany between 2007 and 2025

1) F = forecast (not adjusted) for prices

Source: Destatis (2017), Roland Berger (2017)

Greater acceptance of the green transformation in society is reflected in factors such as the political importance attached to environmental protection, sustainable consumer behavior and the population's assessment of the quality of the environment.

If an awareness of environmental protection and climate action issues is given among key stakeholders – especially among customers, one of companies' principal target groups – then "green issues" will increasingly have a bearing on corporate investment decisions. For example, buying a machine with a highly efficient electric drive system can not only help improve energy efficiency, but can also highlight the company's commitment to mitigating climate change. This correlation can then be leveraged to boost demand for ecofriendly and climate-friendly technologies, making it easier for green innovations to penetrate the market.

Popular acceptance plays a vital role in the funding of environmental protection and climate action measures. Some products and services in the green economy come at a higher cost. Therefore, the more society understands the need to protect the environment and the climate, the more people will be willing to pay for the ecological value added by sustainable products. The pace of the green transformation is significantly influenced by consumer demand. End customers thus have a powerful tool with which to push industry in the direction of sustainable production methods.

Environmental technology and resource efficiency is pivotal to the advance of the green transformation. Green tech players' products, processes and services play a crucial role in mastering ecological challenges. In its capacity as a cross-sector industry, environmental technology and resource efficiency also promotes the green transformation in other branches of industry, injecting powerful stimulus for the ecological modernization of the economy. Integrated approaches and system solutions are two particularly promising aspects.

Digitalization has the potential to support and accelerate the green transformation. On the one hand, digitalization puts in place the technical conditions required for many steps to protect the environment and the climate. For example, by establishing data networks, smart system solutions can realize far greater energy savings than non-automated processes. On the other hand, digitalization facilitates the economies of scale that can make sustainable products and services cost-effective and pave the way to their wider use. Digitalization also enables information to be bundled and visualized in clear, intuitive forms. All these insights can be harnessed to further the development of ecofriendly and climate-friendly technologies and services.

The five dimensions of the green transformation at a glance

How far have companies in Germany progressed with the green transformation? Centered around this key question, interviews were conducted with ten companies originally founded beyond the remit of environmental technology and resource efficiency.

A framework within which to analyze the green transformation at corporate level was staked out in the form of five dimensions of transformation: economic transformation, technological transformation, ecological transformation, employee transformation and institutional transformation (see Figure 94). This framework allowed us to focus on areas to which various green transformation measures can be assigned.

The sections that follow take a close look at how digitalization affects each of these five dimensions and the extent to which it is expediting the transformation to a green economy. Case studies are drawn on to illustrate the points made.

Economic transformation: This is where the process of transformation within a company becomes visible in the form of a wider portfolio of green services. Actively increasing green products' and services' share of total company revenue is one indication of economic transformation. Another obvious sign is the development of green business models (such as energy performance contracting and energy efficiency consulting).

Digitalization influences the economic dimension of the green transformation via an array of different technologies and mechanisms:

- The Internet of Things (IoT) and connectivity enable green business models to be implemented successfully. Smart home system solutions are a case in point: Connected sensors and thermostats share data with each other and, for example, regulate indoor temperatures in response to the current weather and the occupants' preferences. Coordinating thermostats with window sensors raises energy efficiency (see the "innogy SmartHome" case study for more details).

Figure 94: The five dimensions of the green transformation

Transformation

Economic	In the corporate context, economic transformation refers to **earning profits by selling green products**, processes and services and **developing green business models.**
Technological	The technological transformation covers aspects such as **setting up and expanding research and development**, as well as **training and education** in **green technologies.**
Ecological	The ecological transformation at corporate level is understood to mean transformation in areas such as **corporate environmental protection**, **energy independence** based on **renewable sources** and energy and resource efficiency.
Employee	The employee transformation embraces corporate activities to **foster environmental awareness in the company** and to encourage employees to act in an environmentally responsible manner.
Institutional	The institutional transformation includes such activities as **organizational measures** to establish **voluntary obligations**, **self-monitoring**, and consistently environment-friendly management and – in the wider sense – **approaches to environmental management accounting.**

Source: Roland Berger (2017)

- Digitalization can promote dematerialization – witness software that enables virtual product development. In many cases, using this software dispenses with the need to produce prototypes.
- Modern technologies can drive the "greening" of existing products. In the sense used here, "greening" means improving product design by reducing demand for energy and materials and making use of biological materials. One organization has, for example, developed a data projector that uses a new electronic controller and LED light sources to deliver superior energy efficiency.[2]
- The sharing economy concept builds a business model around lending and ownership. Collective use increases the utilization of product capacity during the operating phase, while digitalization provides facilitates easier access to and handling of shared use. Car sharing is a good example of this principle (see the "DriveNow" case study).

Technological transformation: This dimension involves systematically increasing the research and development budget for green technologies and increasing the number of green patents filed.

In the context of technological transformation, digitalization influences the green transformation via a range of different approaches and methods:

- Disruptive technologies can contribute to the development of new kinds of production processes, as shown by the example of trucks from Mercedes-Benz. This company began using 3D printing techniques to produce plastic-based spare parts in 2016. Additive manufacturing now delivers material efficiency that is far superior to conventional production processes (see the "Mercedes-Benz Trucks" case study).
- Digital platforms make it easier to share and exchange data – for example by simplifying green product and process R&D across multiple sites. Green "open innovation" strategies illustrate the point, growing out of a strong focus on applied research and supporting the external development of sustainable products.
- Industry 4.0 and the Internet of Things empower service providers in particular to develop technologies that optimize production processes. Open digital platforms can simplify process steps in industry, for instance. Joining up software, people and processes helps save both material and energy.
- New technologies are making production processes ever more efficient, but can also improve process control. Wet-chemical processes such as cleaning, bleaching and washing, for example, normally consume large quantities of water and chemicals that are hazardous to the environment. The processes involved are complex and interwoven. To dovetail them seamlessly in a way that conserves resources, plant engineering firms such as Voith GmbH are therefore working to develop new types of sensor systems and data-driven process control systems (see the "Voith" case study).

Ecological transformation: Here, the transformation process at the corporate level expresses itself in the form of measures taken to protect environmental media and the natural world and to improve resource efficiency. These measures include using renewable energy, improving energy efficiency and material efficiency, replacing non-renewable resources with renewable ones, expanding environmental management systems within companies, reducing carbon emissions, increasing the recycling rate and taking steps to preserve biodiversity.

Digitalization affects the green transformation in the context of ecological transformation via an assortment of approaches and methods:

- Connecting sensors to a central HQ simplifies the aggregation of digital data, facilitating in-depth analysis of a company's ecological footprint. The ability to share this real-time data also enables processes to be partially automated. The savings on energy consumption made possible by room automation systems are one example: Probes and sensors are used to automate aspects of the control of heating, ventilation and air-conditioning technology, thereby reducing energy consumption.
- Digitalization enables complex processes to be visualized in simplified forms. The resultant ergonomic advances help users make decisions that contribute to superior efficiency. Lufthansa's electronic flight bags highlight the point: Digital data processing supplies pilots with bundled information that can be used to manually determine optimized, more efficient flight routes and enter these in the on-board computer systems (see the Lufthansa case study).
- Companies can make the transition from remedial to preventive environmental protection. The aim is not just to meet but, ideally, to surpass the expectations of investors and customers as well as political

2 See Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF (2012).

demands with regard to sustainability. An example of preventive action to protect the environment comes from the Bosch Group, which draws on modular software, control modules and big data (see the Bosch case study).

Employee transformation: This dimension mostly concerns internal measures to foster environmental awareness among employees. These measures include raising people's awareness of environmental issues (through staff training, for example) and prompting them to think about what they do and why they do it. This dimension of transformation is also concerned with measures that translate environmental awareness into specific actions – implementing environmental management at the workplace, for instance. Another aspect involves the professional skills of employees within their specialist areas. To successfully expand a company's portfolio to include green products and services, staff naturally require suitable qualifications. For example, to move to a distributed power supply structure and rely more heavily on renewable energy sources, a company may need to upskill its specialists who work with heating, ventilation and air-conditioning systems.

Again, digitalization influences the green transformation in the context of employee transformation via a variety of approaches and methods:

- Employee transformation involves encouraging and enabling staff to live out a keen environmental awareness. To reinforce this awareness, companies both offer incentives (to use local public transportation and/or form car pools etc.) and adopt more playful approaches (by setting up "green teams" and organizing "green days" etc.). Many of these activities are publicized via the intranet and other digital communication platforms. German telecoms giant Telekom operates a green car policy that illustrates the point. The company has introduced a system of bonuses and penalties regarding CO_2 emissions from company cars, using software to document fuel consumption and mileage. The aim is to encourage staff to choose smaller vehicles (see the Deutsche Telekom case study).
- Digital infrastructures play a part in promoting forms of work such as home office arrangements, which eliminate the emissions caused by journeys to and from work. Additionally, the use of videoconferences and cloud applications can be an alternative to business travel that harms the climate – such as domestic flights within Germany.
- Media can be used to simplify the transfer of knowledge about issues of relevance to the environment. Digital training courses can motivate staff to adopt sustainable behavior both at work and outside work. Beiersdorf, for example, uses a number of corporate communication channels to encourage employee participation in sustainability initiatives. The company integrates online tools to calculate individual ecological footprints in its existing IT infrastructure and provides awards for employee-initiated sustainability projects (see the Beiersdorf case study).

Institutional transformation: Here, the transformation process manifests itself at the institutional/organizational level as green economy objectives and activities are embedded in the organization. The key issues are management methods and the processes by which social and environmental concerns are integrated in a company's strategy in order to foster sustainable development. Examples include expanding environmental and corporate social responsibility (CSR) management systems (such as environmental management accounting), establishing clear structures of responsibility in the sphere of environmental technology and resource efficiency (for example, by creating a sustainability department), and networking with external environment-related players (for example, engaging in cooperation projects with environmental organizations and other NGOs). This dimension also involves transparent company reporting that is based on established standards and takes account of economic aspects, environmental issues and social concerns alike.

Digitalization affects the green transformation in the context of institutional transformation via an array of different approaches and methods:

- Measuring CO_2 emissions in real time makes it easier and quicker to identify whether compliance with key environmental performance indicators is given. The TUI Group's digital system solution highlights the possibilities opened up by superior data quality. A cloud application captures energy consumption data across the entire group, painting a more accurate picture of the company's ecological footprint (see the TUI case study).
- Environmental management accounting creates a reporting framework for sustainability strategies. VAUDE adopts this approach, defining a sustainability strategy ("green KPIs") for all parts of the company and every step in the product lifecycle. Digitalization enables data gathering to be joined up,

thereby laying the foundation on which to analyze these KPIs (see the VAUDE case study).

- Sustainability rankings compiled by environmental organizations attest to the ongoing nature of corporate social responsibility (CSR) activities. Companies have a keen interest in being listed in these rankings, as this cultivates a positive image in the eyes of stakeholders. Digitalization gives companies a transparent way to demonstrate their compliance with the terms of sustainability certifications (ISO 9001, ISO 14001, EMAS, OHSAS 18001) on relevant websites.
- Digital platforms give organizations a way to reach a wide audience. Environmental protection associations and networks use this digital support as a communication channel to advertise industry initiatives and campaigns. One example from the manufacturing sector is Germany's chemical industry association VCI, which has launched an initiative for sustainability entitled "Chemie hoch 3" (literally: "Chemistry^3").

Economic transformation

The innogy SmartHome

The company and its environment
The launch of innogy SE came as RWE AG's response to the challenges of the structural transition in the energy industry – a transition triggered and advanced by a variety of factors that influence and reinforce each other. These include the liberalization of markets, shifts in energy policy due to climate targets and decentralization. Further changes prompted by digital technologies and business processes are flanking these upheavals. The expansion of renewable energy and the resultant shift toward decentralization have brought significant change to the energy landscape.

"We need to learn to make effective use of larger volumes of electricity produced on a distributed basis from renewable sources."

**Digital helpers in the home –
Energy efficiency at the push of a button**
innogy SmartHome is an addition to the company's portfolio of products to enhance energy efficiency. innogy SE markets thermostats, sensors and wireless switches that work together to make home life a comfortable, resource-saving experience. Heating, lighting and electrical appliances all communicate with each other via the innogy SmartHome hub and a protected wireless network. Ease of use, fast installation and the opportunity to save energy at low cost are opening up access to a wider market.

Digitalization creates the conditions needed by the innogy SmartHome business model. The concept is based on an open platform. Installing transmitter stations (such as radiator thermostats, adapter plugs and ambient thermostats) that are connected to the innogy SmartHome hub establishes connectivity between devices from different manufacturers: washing machines, dishwashers, heaters and lights, for example. Via an application, these electrical devices can thus be switched on and off from any place and at any time. Digital data is collected via the central hub, which aggregates information about the volume, timing and specific location of electricity consumption. This data is available solely to the user.

A specially designed application makes it easy to handle all the devices and appliances involved. This application is the core interface element and contains a personal profile of the user. Function settings in the application allow processes to be automated. When the customer leaves home, for example, the hub automatically lowers the intensity of heating, switches off all lights and makes sure all the windows are closed.

Impact on environmental protection and climate action
On average, homes fitted with innogy SmartHome consume between 10 and 15 percent less energy than the control group, where no digital equipment is installed. Digital connectivity and management significantly improves energy efficiency – using less heat to deliver an agreeable temperature to the individual customer, for example.

The innogy SmartHome concept supports power generation from distributed renewable energy plants. Customers who have installed a photovoltaic system can, for example, specify the time window in which certain appliances are to be used. Green electricity can thus be used at the time when it is generated, effectively increasing the private use of power from renewable sources.

Bottom line
As energy systems become increasingly decentralized, power utilities are having to more closely manage how power is fed into the grids as the new energy policy takes effect. Customers expect modern power utilities not just to supply them with energy, but to provide holistic solutions for a world of decentralized power generation.

www.innogy.com

Economic transformation

DriveNow

The company and its environment

The BMW Group is a Munich-based premium automobile and motorcycle OEM with a global reach. It also provides financing and mobility services. The Group operates 31 production and assembly facilities in 14 countries and employs around 125,000 people worldwide (figures from December 2016). Sixt SE, based in Pullach near Munich, is a global provider of mobility services for corporate customers and private individuals. Founded in 1912, the company today operates in more than 100 countries. The automobile industry today is confronted by an array of challenges. In urban spaces in particular, younger generations see it as less and less important to own a car as a status symbol. Autos are instead seen to have a functional value as vehicles that get you from A to B. At the same time, issues such as air pollution, sustainability and resource efficiency are coming more sharply into focus in politics and society – witness, for example, the statutory limits imposed on emissions.

"For customers, the crucial thing is a digital service that is easy to access."

Don't own it: Drive it! The new business model

DriveNow is a car sharing joint venture that was founded by BMW and Sixt in 2011. Using a stationless model, it makes vehicles available to private and corporate customers and shoulders all variable costs. In return for a fixed one-time fee, customers sign up and can then rent cars in the network on a pay-by-the-minute basis. In Germany, DriveNow currently operates in Munich, Hamburg, Berlin, Cologne and Düsseldorf – five agglomerations where a total of about 3,400 DriveNow vehicles (BMWs and Minis) are currently deployed. Around Europe, DriveNow also provides car sharing services in Vienna, London, Stockholm, Copenhagen, Brussels, Milan, Helsinki and Lisbon. Digitalization is an indispensable prerequisite if BMW and Sixt's car sharing model is to work at a profit. Connectivity across the vehicle fleet assumes a key role. Vehicles communicate with a central hub and with the customer's DriveNow app, enabling customers to locate and book cars that are currently available. The vehicles also pass on information about fuel/charge and oil levels as well as tire pressure. Maintenance and servicing can thus be tailored to each vehicle's precise needs, which has a positive effect on costs.

The business model is completely app-based. Its central feature is a digital service that offers simple, flexible access and is easy to use via a mobile application. Wireless M2M connections let users open and lock vehicles with a keyless system. Also, preset modifications such as the packages booked and the target destination are mapped onto the car itself.

Impact on environmental protection and climate action

The DriveNow business model is helping to improve resource efficiency and reduce emissions compared to conventional individual motorized traffic.

Average capacity utilization per vehicle is five times higher than conventional car usage, which normally averages between 45 and 60 minutes per day. By contrast, DriveNow vehicles currently spend between three and five hours a day on the road. Moreover, car sharing verifiably reduces exhaust emissions. A variety of scientific studies prove that one car sharing vehicle already substitutes for between three and eight privately owned cars. More and more people are abandoning the idea of running their own vehicle inefficiently. Why? Because, alongside other mobility offerings, they have flexible access to shared cars whenever they need one. Fewer vehicles on the road means less traffic circling for parking spaces. And fewer kilometers traveled reduces emissions. In all the cities where it operates, DriveNow deploys a modern fleet that includes e-vehicles. That reduces emissions still further and is also helping drive development of the public charging infrastructure.

Bottom line

BMW is using the shared economy approach to strengthen its position as a mobility service provider, primarily in urban regions. The resultant high capacity utilization per vehicle lowers emissions compared to conventional individual motorized transportation. Looking ahead, car sharing can evolve into an important source of revenue for automotive OEMs.

www.drive-now.com

Technological transformation

Mercedes-Benz Trucks

The company and its environment
Mercedes-Benz Trucks, a business unit of Daimler AG, has assumed a pioneering, technology-leading position among global truck OEMs with its use of 3D printing technology as an innovative, cutting-edge production process in its after-sales activities.

"3D printing makes it economical to manufacture mass products in batches of one."

Innovative production process – Spare parts off the 3D printer
Mercedes-Benz Trucks has been using an additive production process to manufacture spare parts made of plastic since 2016. Using a 3D printer makes production processes for small batch sizes more efficient. Customer service can be improved, because even spare parts from discontinued model series can still be delivered around the globe. In the past, it was becoming less and less economically viable for suppliers to produce these parts. In many cases, production plants and tools had to be kept available and in working order for years. 3D printing has now consigned these challenges to the history books: Every 3D-printed spare part can now be made available on demand, i.e. at short notice anywhere in the world.

Without digitalization, additive manufacturing would be unthinkable. The aim is for 3D printing data records to be generated automatically while a product is still being developed. When a customer orders a spare part, the order can be accepted based on the part number. The printing process is triggered fully automatically. In the future, a central 3D database will store all data needed for the production of spare parts. The printer will connect itself to the central database and can launch production based on the data stored under the specified part number. Production can thus happen in any place and at any time. Another future plan is to set up a number of connected "printing hubs" to facilitate distributed production.

Impact on environmental protection and climate action
The 3D printing process is kind to the environment and conserves resources. As such, it is breaking new ground in after-sales with a production process based on the "one piece demand" concept: the cost-effective production of small quantities of spare parts. 3D printing also delivers superior material efficiency compared to conventional production processes, because additive layers minimize material waste. Since spare and retrofitted parts can still be "reprinted" without difficulty based on the stored data even after lengthy periods, there is also no need for the expense of warehouse storage. At the same time, there is a positive impact on costs, resources and the environment as the very complex process of reusing or disposing of excess materials is eliminated.

Bottom line
Digitalization enables Lufthansa to replace insular approaches to data provisioning with fully integrated digital data preparation. The aim is to completely eliminate the use of paper at every step, and to integrate additional electronic processes.

www.mercedes-benz.de

Technological transformation

Voith GmbH

The company and its environment
Founded in 1867, Voith employs around 19,000 people, posts annual revenue of 4.3 billion euros and has a footprint in more than 60 countries worldwide. It is one of the major family-owned companies in Europe. Voith supplies machinery and solutions to an array of industrial markets: energy, oil and gas, paper, raw materials, and transport/automotive. The advance of connectivity and digitalization will shape mechanical and plant engineering and revolutionize the way in which manufacturers make goods and sell their products and services. The products themselves will be smarter and more efficient in the future. Industry 4.0 will make companies more productive.

"The products we make tomorrow – the turbines and generators, the paper machines and drive systems – will all have a digital copy in the cloud."

Digital innovation – "Papermaking 4.0"
Voith already offers digital products and services to its customers. Every group division has market-ready automation products that will lay the basis for subsequent Industry 4.0 products. Examples include HyCon CS at Voith Hydro, DIWA SmartNet at Voith Turbo and both OnEfficiency and OnCare products at Voith Paper. Voith also wants its new Digital Solutions division to play a key role in the digital transformation. Voith Digital Solutions provides new concepts for automation and IT to serve mechanical and plant engineering in the age of digitalization. One example of how Voith uses digital tools is the papermaking process: Under the heading "Papermaking 4.0", it is making a significant contribution to increasing efficiency, productivity and quality at every link in the paper production value chain – even in legacy plants.

Cutting-edge sensor systems help make the processes in paper machines transparent. These processes can be stabilized and, ultimately, preemptively optimized with actuators and control systems. All this is made possible by interconnecting all kinds of subprocesses and adding information about key conditions, such as quality data from stock production and the properties of the finished product. Automatic dosing avoids the excessive use of valuable resources. Savings on energy, chemicals, fiber and time all add further value.

Impact on environmental protection and climate action
In the interests of cost-effectiveness, processes must be designed and managed as efficiently as possible. One example is the de-inking process in papermaking, which is heavily influenced by the (often fluctuating) quality of the raw material. Manual corrections are laborious, and usually come too late. In other words, neither the yield nor the use of bleaching chemicals is optimally aligned with the prevailing conditions. Voith's OnEfficiency DIP allows resources to be used efficiently and carefully controlled during the production process – leading to correspondingly positive impacts in terms of environmentally friendly processes

Bottom line
The applications rolled out by the Digital Solutions division create a new point of access to digitalization. Plants become more intelligent and, with the aid of sensor systems and online process control, can inject sustainability into the way processes are managed, too. That is especially beneficial to complex processes in which analytics and quality control are retrospective by default. As well as making production more economical, digitalization also plays an active role in protecting the environment.

www.voith.com

Ecological transformation

Lufthansa AG

The company and its environment
The Lufthansa Group is a global aviation group with 540 subsidiaries and equity investments. Headquartered in Frankfurt/Main, it splits its business into three main segments: Premium Hub Airlines, the Eurowings Group and Aviation Services.

Aviation is a very fast-moving industry that follows the lead given by changing customer needs. On the one hand, low-cost airlines that service the needs of price-sensitive customers are putting pressure on margins in point-to-point traffic within Europe. On the other hand, competition is also growing from premium hub airlines that target quality leadership. The Lufthansa Group is keen to strengthen its market position through technological developments and synergies across its three key segments.

"By increasing connectivity and analyzing real-time data, we want to drive the sustainability of aircraft operation."

Paperless cockpit
Lufthansa has prepared the ground for implementation of the paperless cockpit. One aspect is the improvements it has made to the Electronic Flight Bag (EFB), a computer platform designed to help pilots prepare and operate flights. Another is the introduction of the electronic Flight Folder (eFF), a new software tool that supplies pilots with briefing information in a clear form to support their decision-making.

EFB and eFF are both parts of Lufthansa's "e-enabling" program, which is advancing the digitalization of in-aircraft processes. The electronic Flight Folder visualizes briefing information and uses color coding. An ergonomic user interface makes it easier to switch between different categories of information and find what is truly relevant. A synchronization function across the different EFBs in the cockpit improves collaboration among the crew. A computing function featuring fuel information for the flight schedule and reference values from previous flights helps pilots with decisions about the quantity of fuel to be taken on board depending on weather conditions. During the flight, an electronic navigation log further assists the pilot with strategic fuel management. Pilots thus have an accurate picture of the fuel situation at all times, both before and during the flight. That improves flight safety as well as economizing on fuel, as every kilogram carried in the air costs more fuel to transport it.

The e-enabling program is rooted in data, data connectivity, in-flight connectivity (between the aircraft and systems on the ground) and on-board connectivity (between the EFBs on board and the flight systems). The EFB application "Flight Profile", for example, uses the electronic briefing data, real-time data from the on-board electronics systems and both measured and predicted wind speeds to calculate the most economical speed and altitude for the remainder of the flight.

Impact on environmental protection and climate action
The digital infrastructure developed by Lufthansa helps pilots with decision processes relating to flight paths, kerosene quantities etc., all of which ultimately improve resource efficiency and reduce greenhouse gas emissions.

Bottom line
Digitalization enables Lufthansa to replace insular approaches to data provisioning with fully integrated digital data preparation. The aim is to completely eliminate the use of paper at every step, and to integrate additional electronic processes.

www.lufthansa.com

Ecological transformation

Bosch Group

The company and its environment
Headquartered in Stuttgart, the Bosch Group is a global supplier of technology and services. Its core activities are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology.

“We need to pro-actively come up with interfaces to different IT systems and target seamless, end-to-end data collection.”

Increasing pressure to innovate and ever fiercer international competition are putting wind in the sails of the technology and service industry. The political framework is one driver in the industrial context; another is the demands of investors and customers with regard to sustainability. All these groups are calling for the economically and ecologically sound use of resources.

Green factories – Sustainable use of resources
The Bosch Group sets its own sustainability targets as part of its environmental management system. The office buildings and production halls at its “green” factories reflect an ecofriendly design that encourages the sustainable use of resources.

Digitalization is imperative if the Bosch Energy Platform software is to be deployed and green factories are to be established. The modular software lays the foundation for improved energy efficiency in the Bosch Group’s buildings. The Bosch Energy Platform gathers relevant output and energy consumption data across multiple sites, facilitating comparison with historical data. Automated data presentation and visualization of the overall ecological footprint on an ergonomic user interface enhances transparency. That makes it easier to identify where further optimization is possible. One component of the Energy Platform software is a monitoring system that automatically detects consumption anomalies. Clearly focused responses can thus be identified at an early stage to minimize energy consumption.

Installing connected control modules (such as the IndraLogic PLC) in the production halls paves the way to a better, automated communication concept. Joining up different climate sensors makes it possible to operate a semi-automated sunshade system, for example. Weather sensors beam up-to-the-minute data to a central platform that aligns a mobile sunshade installation with the angle of the sun’s rays. This arrangement avoids 80 percent of the energy normally needed (for cooling systems etc.) in relation to solar radiation. The IT system also allows lighting in the production facilities to be adjusted in line with the weather conditions outside the building. Here too, the energy needed by the lighting system is slashed by as much as 60 percent.

Impact on environmental protection and climate action
The plant in Abstatt is a good example of how ecofriendly construction can enable the reduction of CO_2 emissions. Heat recovery units and heat pumps are among the equipment installed here, allowing 5,000 tonnes of CO_2 to be saved every year.

As the Bosch Group continues to develop its environmental management program, it is shifting the focus from curing damage to the environment to preventing it in the first place. Internally defined sustainability goals are stricter than the environmental protection targets imposed from the outside. The office building in Singapore, for example, consumes around a third less energy than is prescribed by national legislation.

Bottom line
The Bosch Group is committed to preventive environmental protection measures at its various sites. The control modules described above are currently installed and optimizing efficiency at about half of the company’s factories worldwide.

www.bosch.com

Employee transformation

Deutsche Telekom

The company and its environment
Deutsche Telekom ("Telekom") is a leading European telecommunications provider. It sells products and services in the following business lines: fixed network/broadband, mobile communications, Internet/Internet TV, and information and communication technology. Headquartered in Bonn, this publicly traded group employs around 218,000 people worldwide and has a footprint in more than 50 countries.

To stay successful going forward, the company is evolving from a traditional telephone company to a completely new kind of service company. Its core business – operating and selling networks and terminal equipment – remains in place as the foundation. At the same time, the group is aggressively occupying new areas of business that open up fresh growth opportunities. Firmly convinced that economic, social and ecological considerations are mutually compatible, Telekom is committed to acting responsibly at every link in its value chain.

"Employees are taking a more flexible view of mobility. Several options are being well received."

Green car policy: The sustainable way to get around
Telekom MobilitySolutions, a Deutsche Telekom subsidiary, operates the group's vehicle fleet. Its goals for this fleet are cost-effective operation, sustainable development and the reduction of direct CO_2 emissions. One important aspect is raising its employees' awareness of ecological concerns and encouraging ecofriendly and climate-friendly behavior. A system of bonuses and penalties achieves this goal, together with the introduction of incentives for alternative mobility concepts. Staff awareness of being personally responsible for mitigating climate change is also reinforced by the company's offer of ecofriendly driver training, job tickets, rent-a-bike systems at 31 locations around Germany, and a salary conversion model for bicycles and e-bikes. Employees also have the option of using a fully refunded rail card instead of a company car.

Digitalization too is having a positive impact on mitigating climate change. Efficient practices are ensured by a central fleet management system that integrates everything from initial orders to control of repair shop activities to vehicle marketing.

Mileage and fuel consumption are recorded and analyzed. Via a customized user portal, drivers of company vehicles can thus compare their fuel consumption with average values for similar vehicles in the fleet. Cultivating awareness of fuel consumption has been proven to contribute to a more environmentally friendly driving style.

The alternative mobility concepts made available via a digital infrastructure likewise develop employees' sensitivity to ecological issues. A shuttle application lets employees and/or their guests book travel with company buses – to the Cologne/Bonn and Frankfurt Airports, for example, or to the ICE railway station in Siegburg/Bonn. Journeys to heavily frequented destinations can therefore be bundled, reducing expenditure on taxis and curbing the use of fuel and parking fees for business vehicles. The shuttle buses also have wireless LAN to enable staff to work in comfort on the road. About 120,000 passengers a year make use of this internal shuttle service (data from December 2016). An alternative mobility solution for middle-distance business travel is to use a car hire service. Vehicles in this pool can be booked 24/7 via an online portal. A dedicated app will also be available in the future.

An RFID card gives customers keyless, round-the-clock access to the vehicle they have hired.

Impact on environmental protection and climate action
Thanks to the green car policy and the individual mobility concepts, the vehicle fleet's CO_2 emissions were cut to an average of 110 grams per kilometer by the end of 2015. That put Deutsche Telekom well within the threshold of 130 grams of CO_2 per kilometer prescribed by the European Union.

Bottom line
Digitalization has opened up an array of mobility services for employees that support intermodal and multimodal transport. Using an application or a website allows employees to identify and book the right mobility concept – shuttle bus, company car, hired car or bicycle – for each situation and every requirement.

www.telekom.de

Employee transformation

Beiersdorf

The company and its environment
Beiersdorf is a publicly traded enterprise with 19,000 employees spread across more than 160 subsidiaries worldwide (data from December 2017). It breaks down into two business segments: Consumer, which manufactures skin and body care products; and tesa, which manufactures self-adhesive system and product solutions for industrial customers and consumers. Consumer – whose stand-out brands include NIVEA, Eucerin, La Prairie, 8x4 and Hansaplast – is the main focus of its activities.

"We care." – Strategy to bundle sustainability goals for the years ahead
At Beiersdorf, commitment to sustainability is a long-standing tradition. The "We care." sustainability strategy lived out by its Consumer segment focuses sharply on responsible growth and building sustainability into every link in the value chain. The strategy centers around three pillars – Products, Planet and People – and has set concrete sustainability targets for 2020 and 2025. A series of actions have also been launched to measure the whole company's progress toward realizing these targets.

"We care." – The sum total of many "I cares"
Employee engagement and a three-fold policy of informing, involving and inspiring have been central to the "We care." program from the outset. "Again and again, we have made it clear that our efforts toward sustainability can succeed only if every one of our people plays their part," says Dorle Bahr, Head of Environmental Sustainability, outlining the basic tenets of the initiative. "Only then will the whole company develop the tremendous potency we need to meet our ambitious targets." In other words, "We care." is the sum total of many individual "I care" goals.

To ensure that staff around the globe buy into the strategy, Beiersdorf launched an extensive and ongoing internal communication offensive flanked by a number of employee engagement campaigns. It began with a campaign of posters and videos in which various colleagues spelled out their personal "I care" commitments, inspiring others to take action too. This was followed by "think planet", "A closer look at products" and "All about people": further campaigns designed to help people understand sustainability and encourage individuals to take the initiative. One example of the

"Although the work environment is becoming increasingly flexible, we've found a way to get the message of environmental issues across."

employees' engagement is support for the Foodsharing e.V. program, which links the responsible use of resources to social action. Since 2013, Beiersdorf has regularly donated fresh but unused food from its company restaurant in Hamburg to social institutions around the city.

Digital company platforms played a pivotal role in establishing both the "We care." strategy and the individual campaigns around the world. The company's "BlueNet" intranet primarily shares information about the strategy, its goals and progress toward achieving them. At the same time, the online collaboration platform "blueplanet" focuses on making materials available and promoting interaction between employees in the regions, in the form of chat forums, for example. Additional videos (some of them with user-generated content in which employees sketch their personal commitment to sustainability), the interactive tool www.myimpactontheplanet.com to measure the individual's ecological footprint, and a digital quiz in which employees can manage and vary the process of manufacturing a product and learn about the sustainability of "their" product round off the digital side of the "We care." initiative.

Bottom line
Beiersdorf harnesses a range of digital communication channels and media to raise awareness of sustainability issues among its workforce. This policy has succeeded in anchoring the concerns of "We care." throughout the group and achieving ambitious sustainability targets.

www.beiersdorf.de/nachhaltigkeit

Institutional transformation

TUI AG

The company and its environment
The TUI Group is a listed tourism group with global operations. Headquartered in Berlin and Hanover, it employs around 67,000 people worldwide and provides customers with services at every link in the tourism value chain. Customers can book travel via travel agencies and online portals. TUI Fly flies them to the TUI Group's hotels and cruisers. The needs of demanding customers are changing the market. The trend is toward authentic travel experiences and remote destinations, such as Asia and the Caribbean. At the same time, stronger emphasis is being placed on sustainability and resource efficiency in the travel and tourism industry.

"We want to reconcile growth to sustainability."

FTSE4Good Global Benchmark Index – Recognition for commitment to sustainability
The TUI Group has been listed on the FTSE4Good Global Benchmark Index since 2010. This series of indexes from the London-based FTSE organization lists companies that demonstrate exceptional commitment in the field of corporate social responsibility. It attests that, in terms of sustainability and corporate governance, the activities of the listed companies are significantly better than the industry average (best in class). The positive criteria for acceptance in the FTSEGood Index Serie are based on globally recognized norms such as those enshrined in the UN Global Compact and the Human Rights Convention. Companies listed in the index must implement steps toward ecological sustainability, respect and promote compliance with human rights, ensure good working conditions and transparency in the supply chain, prevent corruption and advance the mitigation of climate change.

Two TUI initiatives are indicative of the group's commitment: At its travel agencies in England, energy dashboards visualize the building's CO_2 emissions in real time and juxtapose this data with the applicable energy-saving targets. In just three years, measures derived from the displays on these dashboards contributed to a 24 percent reduction in CO_2 emissions at these agencies.

TUI Cruises equips its vessels with a new kind of energy monitoring and management (EMMA) system (for voyage and trim optimization). This system links real-time data from multiple sources to optimize the trim of the vessel. Weight, currents, weather conditions and other data is drawn on to calculate the most efficient route. Newly built vessels added to the fleet are also fitted with an intelligent energy management system that can save up to ten tonnes of fuel per day. (To put that in perspective: Average daily fuel consumption is around 200 tonnes.)

Impact on environmental protection and climate action
Environmental protection is an integral part of TUI's corporate strategy. This fact, plus compliance with the ISO 14001 standard, is helping to reduce greenhouse gas emissions. The TUI Group has set itself the goal of shaving 10 percent off its carbon intensity between 2015 and 2020. All of its subsidiary groups are taking action to this end. In fiscal 2014/15, for example, TUI Fly successfully reduced CO emissions per passenger kilometer by 2.3 percent year on year. One of the group's key objectives is to promote a sustainable tourism industry. By 2020, it wants to offer sustainable vacation travel in accordance with Global Sustainable Tourism Council (GSTC) certification to 10 million travelers a year (2015: 5.6 million). Additionally, the TUI Group has launched initiatives such as the TUI Care Foundation to step up protection of nature and the environment at holiday destinations. On Lanzarote, for example, it is supporting the island's tradition of organic winegrowing.

Bottom line
Within the TUI Group, digitalization is accelerating the advance of sustainable tourism. The company uses a cloud application to capture energy consumption data across the entire group and visualize its ecological footprint. The system solution delivers high-quality data and gives the group better management and control of environment-related activities.

The TUI Group shoulders ecological responsibility for the destination countries in which it operates. It is increasing local engagement and cooperating with regional partners to promote sustainable tourism.

www.tui.com

Institutional transformation

VAUDE Sport GmbH & Co. KG

The company and its environment
VAUDE Sport GmbH & Co. KG is based in Tettnang, Baden-Württemberg, southern Germany, and was established in 1974 as a supplier of mountain sports gear. Today, the family-owned company operates in three business segments: Mountain Sports, Bike Sports and Packs 'n' Bags. Its product range includes clothing, shoes, backpacks, sleeping bags and thermal sleeping mats, tents, bags and travel baggage.

Growth in the outdoor industry has been sluggish for some years. Predatory competition among outdoor providers is correspondingly fierce, and the market is now visibly consolidating. On the demand side, values are perceivably changing, as sustainability becomes more and more important to customers. The outdoor industry's nature-loving, sport-crazy clientele in particular has exacting standards when it comes to compliance with ecological and social criteria. For providers, sustainability is a powerful differentiator.

Going green puts VAUDE in the black
At VAUDE, digitalization simplifies and accelerates environmental management accounting. As soon as EMAS certification[3] was introduced in 2008, VAUDE began systematically gathering data of relevance to sustainability up and down the value chain and across its individual business segments. Its innovative approach to environmental management accounting won the company a prize from Germany's Péter Horváth Foundation. It is based on the quality of data collection, the way data is joined up, analyzed and interpreted, and permanent improvement of the data quality. Trends can be recognized and processes optimized as a result.

Internal connectivity makes it possible to measure sustainability targets all along the value chain. The aim is to realize end-to-end data integration – from the material producers to final packaging – by introducing an enterprise resource planning (ERP) system. A stable supplier system is tremendously important in this context. End-to-end data integration makes it possible to measure the CO_2 footprint of each individual product, for example. Via digital communication channels, customers of and stakeholders in this family business are kept up to date on how VAUDE is complying with economic, ecological and social sustainability criteria. VAUDE uses its own website and social media platforms to report on implementation of its environmental management systems (ISO 14001, EMAS) and compliance with CSR standards (Fair Wear Foundation, German Sustainability Code, Economy for the Common Good). Sustainability is also at the heart of many of its digital marketing campaigns.

"We can successfully implement our sustainability strategy in all business segments only if we tread this path hand in hand with our suppliers."

Impact on environmental protection and climate action
To put its sustainability strategy into practice, VAUDE has developed a system of indicators for all its business segments. To this end, the VAUDE Green Shape criteria were formulated in 2010 and tightened up in 2015. Green Shape is an evaluation system for outdoor products that VAUDE developed itself. VAUDE gives the Green Shape label to products manufactured using ecofriendly processes that help conserve resources. The Green Shape criteria apply not only to materials, but to the entire product lifecycle – from product development to production to product care and the options for recycling or disposal. Alongside the principal fabrics, every element – including buttons, thread and other materials – must satisfy the Green Shape requirements. The Green Shape evaluation system is based on the bluesign® system[4], but does go beyond the criteria for this textile material certification on some points.

Bottom line
VAUDE uses environmental management accounting as a driver of green innovation. It is increasing its use of secondary raw materials recovered from recycling processes. Digitalization enables comprehensive, joined-up data to be used to optimize processes.

www.vaude.com

3 Eco-Management and Audit Scheme – EMAS is a voluntary instrument introduced by the European Union to improve corporate environmental protection. It is designed to help companies of all sizes and legal forms to continually improve their environmental performance. It is regarded as the strictest and most comprehensive environmental management system in the world.

4 The bluesign® system requires companies to observe five principles throughout the entire production chain: resource productivity, consumer protection, job security and pollution of neither waste nor wastewater.

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A

acatech – Deutsche Akademie der Technikwissenschaften e.V. (2013): Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4.0 [www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Abschlussbericht_Industrie4.0_barrierefrei.pdf; accessed on April 8, 2017]

Arbeitsgemeinschaft Energiebilanzen e.V. (2016): Auswertungstabellen zur Energiebilanz Deutschland 1990 bis 2015 [www.ag-energiebilanzen.de/10-0-Auswertungstabellen.html; accessed on July 31, 2017]

B

Bayerisches Landesamt für Umwelt (2016): Spurenstoffe im Wasser [www.lfu.bayern.de/umweltwissen/doc/uw_125_spurenstoffe.pdf; accessed on March 25, 2017]

BDL – Bundesverband der Deutschen Luftverkehrswirtschaft (2017): Klimaschutzreport 2017, Berlin

Becker, Joachim (2017): China unter Strom. Süddeutsche Zeitung, January 28/29, 2017

BP Statistical Review of World Energy June 2017 [www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf; accessed on July 27, 2017]

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2007): GreenTech made in Germany. Umwelttechnologie-Atlas für Deutschland, Munich

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2009a): GreenTech made in Germany 2.0. Umwelttechnologie-Atlas für Deutschland, Munich

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2009b): Umwelttechnik-Dienstleistungen. Treiber für ökologische Modernisierung und Beschäftigung, Berlin

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (eds.) (2012): GreenTech made in Germany 3.0. Umwelttechnologie-Atlas für Deutschland, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2015a): Erstes globales Klimaschutzabkommen beschlossen – press release dated December 12, 2015 [www.bmub.bund.de/pressemitteilung/klimaschuetzer-schreiben-geschichte/; accessed on April 2, 2017]

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2015b): Klimaschützer schreiben Geschichte – press release dated December 12, 2015 [www.bmub.bund.de/pressemitteilung/klimaschuetzer-schreiben-geschichte/; accessed on April 2, 2017]

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2015c): GreenTech made in Germany 4.0. Umwelttechnologie-Atlas für Deutschland, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016a): Hendricks: „Paris wirkt" – press release dated November 18, 2016 [www.bmub.bund.de/pressemitteilung/hendricks-paris-wirkt/; accessed on April 2, 2017]

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016b): Klimaschutzplan 2050: Kabinett beschließt Wegweiser in eine klimaneutrales Deutschland – press release dated November 14, 2016 [www.bmub.bund.de/pressemitteilung/klimaschutzplan-2050-kabinett-beschliesst-wegweiser-in-ein-klimaneutrales-deutschland/; accessed on April 2, 2017]

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016c): Klimaschutz in Zahlen, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016d): Den ökologischen Wandel gestalten. Integriertes Umweltprogramm 2030, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2016e): Abfallwirtschaft in Deutschland. Fakten, Daten, Grafiken, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017a): Hendricks: Deutsche Nachhaltigkeitsstrategie 2016 ist klares Bekenntnis zum Schutz unseres Planeten – press release dated January 11, 2017 [www.bmub.bund.de/pressemitteilung/hendricks-deutsche-nachhaltigkeitsstrategie-2016-ist-klares-bekenntnis-zum-schutz-unseres-planeten/; accessed on April 2, 2017]

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017b): Klimaschutz in Zahlen. Fakten, Trends und Impulse deutscher Klimapolitik. Issue 2017, Berlin

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2017c): Klimaschutz in Zahlen: Der Sektor Verkehr [www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutz_in_zahlen_verkehr_bf.pdf]

Bundesministerium für Verkehr und digitale Infrastruktur (eds.) (2015): Stufenplan Digitales Planen und Bauen [www.bmvi.de/SharedDocs/DE/Publikationen/DG/stufenplan-digitales-bauen.pdf?__blob=publicationFile; accessed on April 30, 2017]

Bundesministerium für Wirtschaft und Energie (2014): Hoher Energieverbrauch des Gebäudesektors [www.bmwi-energiewende.de/EWD/Redaktion/Newsletter/2014/22/Meldung/hoher-energieverbrauch-des-gebaeudesektor.html; accessed on July 31, 2017]

Bundesministerium für Wirtschaft und Energie (2017a): Erneuerbare Energien [www.bmwi.de/Redaktion/DE/Dossier/erneuerbare-energien.html; accessed on July 31, 2017]

Bundesministerium für Wirtschaft und Energie (2017b): Energieeffizienz in Zahlen, p. 9 [www.bmwi.de/Redaktion/DE/Publikationen/Energie/energieeffizienz-in-zahlen.pdf?__blob=publicationFile&v=14; accessed on July 27, 2017]

Bundesministerium für Wirtschaft und Energie (2017c): Nationaler Energieeffizienz-Aktionsplan (NEEAP) 2017 der Bundesrepublik Deutschland [www.bmwi.de/Redaktion/DE/Publikationen/Energie/nationaler-aktionsplan-energieeffizienz-neeap.pdf?__blob=publicationFile&v=14; accessed on July 27, 2017]

Bundesministerium für Wirtschaft und Energie (2017d): press release dated March 16, 2017: Bundesregierung schlägt G20 Ressourcenpartnerschaft vor – Weltressourcenrat präsentiert Ergebnisse zum globalen Ressourcen- und Rohstoffverbrauch [www.bmwi.de/Redaktion/DE/Pressemitteilungen/2017/20170316-bundesregierung-schlaegt-g20-ressourcenpartner-weltressourcenrat-ergebnisse-globalen-ressourcen-rohestoffverbrauch.html; accessed on March 17, 2017]

Bundesministerium für Wirtschaft und Energie (2017e): Der starke Kern der deutschen Wirtschaft [www.bmwi.de/Redaktion/DE/Dossier/moderne-industriepolitik.html; accessed on March 18, 2017]

Bundesministerium für Wirtschaft und Energie (2017f): Moderne Industriepolitik [www.bmwi.de/Redaktion/DE/Dossier/moderne-industriepolitik.html; accessed on April 8, 2017]

Bundesregierung (eds.) (2017): Deutsche Nachhaltigkeitsstrategie. New edition, 2016, Berlin

C

CHEMIE.DE Information Service GmbH (2017): Wasserstoffherstellung [www.chemie.de/lexikon/Wasserstoffherstellung.html; accessed on August 3, 2017]

China Observer (2016): Über eine Million Hektar Ackerland in China von Dürre betroffen [www.china-observer.de/index.php/2016/04/13/uber-eine-million-hektar-ackerland-in-china-von-durre-betroffen/; accessed on March 14, 2017]

Christensen, Clayton M. (1997): The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail, Boston

Clean Energy Partnership (2017): Wer ist die CEP? [https://cleanenergypartnership.de/clean-energy-partnership/wer-ist-die-cep/?scroll=true; accessed on August 3, 2017]

CPC Strategy (2015): 15 Leading Product Information Management (PIM) Software Solutions for Retailers - CPC Strategy [www.cpcstrategy.com/blog/2015/02/15-pim-software-retailers/; accessed on April 30, 2017]

Cylon (2017): Cylon | Intelligente Energiesteuerung [www.cylon.com/de/; accessed on April 30, 2017]

D

Deutsche Bank Research (2016): Hochburg der Stabilität: Was Deutschland so erfolgreich macht [www.deutsche-bank.de/pfb/data/docs/20161215_Hochburg_der_Stabilitaet__Was_Deutschland_so_erfolgreich_macht.pdf; accessed on July 31, 2017]

Deutsche Bank Research (2017): Unsicherheit bremst Investitionen aus [www.dbresearch.de/PROD/DBR_INTERNET_DE-PROD/PROD0000000000432852/Unsicherheit_bremst_Investitionen_aus.pdf; accessed on August 16, 2017]

Deutsche Rohstoffagentur (2017): DERA-Rohstoffliste 2016 [www.deutsche-rohstoffagentur.de/DERA/DE/Downloads/rohstoffliste-2016-zusammenfassung.pdf?__blob=publicationFile&v=4; accessed on July 28, 2017]

Deutsche Telekom AG (2017): QIVICON Die Plattform für Smart Home [www.qivicon.com/de/vorteile/?mlid=2221.14.1127219.f216b0f55785aee97c4102727e116189...0.1461934143.1.1464526143; accessed on April 30, 2017]

Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA) (2015): Möglichkeiten der Elimination von anthropogenen Spurenstoffen, p. 8 [www.dwa.de/dwa/shop/shop.nsf/Produktanzeige?openform&produktid=P-DWAL-9VE7VK; accessed on March 25, 2017]

Deutsche Welle (2016) [www.dw.com/en/quote-ban-ki-moon-un/a-36213909; accessed on April 8, 2017]

Deutscher Bundestag (2014): Der Rebound-Effekt: Störendes Phänomen bei der Steigerung der Energieeffizienz, Wissenschaftliche Dienste 16/14, June 2014 [www.bundestag.de/blob/282726/85e2970ac3cda746a05541a0269eda69/der-rebound-effekt--stoerendes-phaenomen-bei-der-steigerung-der-energieeffizienz-data.pdf; accessed on August 2, 2017]

Deutschlandfunk (2015): Rüsten für den Wassermangel [www.deutschlandfunk.de/brasilien-ruesten-fuer-den-wassermangel.1773.de.html?dram:article_id=311324; accessed on March 14, 2017]

DRS DefectRadar GmbH (2017) [www.defectradar.com; accessed on April 30, 2017]

E

E.ON Energie Deutschland GmbH (2017): SmartGrid: Das Netz denkt mit [www.eon.de/pk/de/energiezukunft/erneuerbare-energien/technologie/intelligente-verteilung/smartgrid.html; accessed on April 30, 2017]

Earth Overshoot Day (2017) [www.overshootday.org/newsroom/press-release-german/; accessed on August 2, 2017]

Eastman, C. (eds.) (2011): BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors, 2. ed. Hoboken, NJ

Eder, Stephan (2016): Windmühlen kommen auf See an die Leine, in: VDI Nachrichten vom September 29, 2016 [www.gicon-sof.de/fileadmin/GICON_SOF/presse/160929_VDI_Nachrichten_Seite_21.jpg; accessed on March 25, 2017]

eLife (2017): Ahoi Zukunft: Schwimmende Windräder [https://elife.vattenfall.de/zukunft/schwimmende-windraeder/; accessed on March 25, 2017]

EnOcean GmbH (2017) [www.enocean.com/de/; accessed on April 30, 2017]

Europäische Kommission (2017): press release dated June 1, 2017: Statement by Climate Action and Energy Commissioner Miguel Arias Cañete on the US announcement to withdraw from the Paris Agreement [http://europa.eu/rapid/press-release_STATEMENT-17-1513_en.htm; accessed on July 26, 2017]

Eurostat (2017) [http://ec.europa.eu/eurostat/tgm/web/_download/Eurostat_Table_tsdcc210PDFDesc_20028956-8e27-4eba-93cd-57a6b980e5d4.pdf; accessed on March 12, 2017]

F

Fichter, Klaus/Weiß, Ralf (2016): Green Economy Gründungsmonitor 2015 [www.borderstep.de/wp-content/uploads/2016/09/Gr%C3%BCndungsmonitor-2015.pdf; accessed on July 31, 2017]

Fleig, Jürgen (2017): Disruptive Innovationen: Die Regeln der Branche radikal verändern, business-wissen.de [www.business-wissen.de/artikel/disruptive-innovationen-die-regeln-der-branche-radikal-veraendern/; accessed on April 30, 2017]

Fraunhofer-Einrichtung für Systeme der Kommunikationstechnik ESK (eds.) (2011): Smart Grid Communications 2020. Fokus Deutschland [www.esk.fraunhofer.de/content/dam/esk/dokumente/SmartGrid_Studie_dt_web_neu.pdf; accessed on August 1, 2017]

Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF (2012): 20 Jahre fraunhofer iof [www.iof.fraunhofer.de/content/dam/iof/de/documents/wir/Festbrosch%C3%BCre-20-Jahre-L%C3%B6sung-mit-Licht.pdf; accessed on June 7, 2017]

Fraunhofer-Projektgruppe für Wertstoffkreisläufe und Ressourcenstrategie IWKS (2017) [www.iwks.fraunhofer.de/de/iwks-abteilungen/urbanmining.html; accessed on March 26, 2017]

Fücks, Ralf (2016): Freiwillige grüne Revolution, in: IP Zeitschrift für internationale Politik, March/April 2016, page 42-45

G

General Assembly of the United Nations (2015): Siebzigste Tagung, Tagesordnungspunkte 15 und 116, document no. A/70/L.1, German version

German Trade & Invest (2016): China forciert Umweltschutz [www.gtai.de/GTAI/Navigation/DE/Trade/Maerkte/suche,t=china-forciert-umweltschutz,did=1480830.html; accessed on March 19, 2017]

Global Wind Energy Council (2017): Strong Outlook for Wind Power – press release dated April 25, 2017 [www.gwec.net/strong-outlook-for-wind-power/; accessed on August 1, 2017]

Google Deutschland (eds.) (2017): Damit sich Schiffe nicht im Weg stehen, in: Aufbruch Daten

Grupp, Michael (2016): IE3-Norm. Gegen den Strom, in: Industrieanzeiger [http://industrieanzeiger.industrie.de/themen/energieeffizienz/gegen-den-strom/; accessed on July 30, 2017]

H

Hamburg Port Authority (2017a): Güterumschlag und Potenzialprognosen [www.hafen-hamburg-2025.de/de/wachstum/Seiten/Umschlagstatistik.aspx; accessed on April 30, 2017]

Hamburg Port Authority (2017b): smartPORT logistics [www.hamburg-port-authority.de/de/smartport/logistics/Seiten/Unterbereich.aspx; accessed on April 14, 2017]

Heinrich Böll Stiftung (2017): Perspektiven der US-Klimapolitik unter Donald Trump [www.boell.de/de/2017/04/26/perspektiven-der-us-klimapolitik-unter-donald-trump; accessed on July 26, 2017]

Hüther, Michael (2015): Defizite in der Spitzentechnologie? [www.iwkoeln.de/presse/gastbeitraege/beitrag/michael-huether-in-forschung-lehre-defizite-in-der-spitzentechnologie-236352; accessed on July 31, 2017]

I

ICONAG Leittechnik GmbH (2017) [www.iconag.de/; accessed on April 30, 2017]

Institut für Mittelstandsforschung (2017): KMU-Definition des IfM Bonn [www.ifm-bonn.org/definitionen/kmu-definition-des-ifm-bonn/; accessed on March 31, 2017]

Institute for Advanced Sustainability Studies (IASS) (2014): IASS Fact Sheet 2/2014. CO2 als Wertstoff? [www.iass-potsdam.de/sites/default/files/files/rz_fact_sheet_140708_digital_0.pdf; accessed on March 21, 2017]

Intergovernmental Panel on Climate Change (2014a): Klimaänderung 2014. Synthesebericht. Zusammenfassung für politische Entscheidungsträger [www.de-ipcc.de/_media/IPCC-AR5_SYR-SPM_vorlaeufige-Uebersetzung_Dez2015.pdf; accessed on March 19, 2017]

Intergovernmental Panel on Climate Change (2014b): 5. Sachstandsbericht, Arbeitsgruppe 3 [www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter1.pdf; accessed on August 2, 2017]

Internationale Energie-Agentur (2016a): World Energy Outlook. Zusammenfassung German Translation, [www.iea.org/publications/freepublications/publication/WEO2016_ExecutiveSummary_Germanversion.pdf; accessed on March 18, 2017]

International Energy Agency (2016b): Energy Efficiency Market Report 2016, Paris

International Energy Agency (2016c): CO_2 emissions from fuel combustion. Highlights 2016 [www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustion_Highlights_2016.pdf; accessed on September 27, 2017]

International Energy Agency (2017): Transport [www.iea.org/topics/transport/; accessed on March 18, 2017]

International Transport Forum (2017a): Transport Outlook 2017. Zusammenfassung in Deutsch [www.keepeek.com/Digital-Asset-Management/oecd/transport/itf-transport-outlook-2017/summary/german_2156df17-de#.WM17E2_hCUk; accessed on March 19, 2017]

International Transport Forum (2017b): press release dated on January 30, 2017: CO_2 Mitigation Measures for Transport Will Not Achieve Climate Ambitions [www.itf-oecd.org/co2-mitigation-measures-outlook-2017-media-release; accessed on March 18, 2017]

ITIZZIMO AG (2017) [www.itizzimo.com/; accessed on April 30, 2017]

K

Karlsruher Institut für Technologie (2016): Power-to-Liquid: Erste Kompaktanlage im Pilotbetrieb. Press release dated November 9, 2016 [www.kit.edu/downloads/pi/KIT_PI_2016_156_Power-to-Liquid%20-%20Erste%20Kompaktanlage%20im%20Pilotbetrieb.pdf; accessed on March 19, 2017]

katholisch.de (2016): Enzyklika „Laudato si“ [www.katholisch.de/aktuelles/themenseiten/enzyklika-laudato-si; accessed on April 9, 2017]

Knappe, Florian/Lansche, Jens (2010): Optimierung der Verwertung mineralischer Bauabfälle in Baden-Württemberg, Heidelberg

Kreutzer, Ralph T. (2017): Treiber und Hintergründe der digitalen Transformation, in: Schallmo, Daniel R.A. et al. (eds.) (2017): Digitale Transformation von Geschäftsmodellen. Grundlagen, Instrumente und Best Practices, Wiesbaden, page 34-58

L

Lacy, Peter/Rutqvist, Jakob/Buddemeier, Philipp (2015): Wertschöpfung statt Verschwendung: die Zukunft gehört der Kreislaufwirtschaft, Munich

Lünendonk GmbH (2015), „5 vor 12 – Die digitale Transformation wartet nicht“, Lünendonk, Lünendonk®-Whitepaper, 2015

Lumenaza GmbH (2017) [www.lumenaza.de; accessed on April 30, 2017]

M

Magazino GmbH (2017) [www.magazino.eu/toru/; accessed on April 30, 2017]

N

Naisbitt, John (2015): „Der Horizont reicht meist nur bis zum nächsten Wahltag." Interview with John Naisbitt, quoted in: APuZ, Aus Politik und Zeitgeschichte, Vol. 65, 31–32/2015

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017a): S-PRESSO – Praxiserprobung von wasserstoffbetriebenen Omnibussen in Stuttgart und Umgebung [www.now-gmbh.de/de/nationales-innovationsprogramm/projektfinder/verkehr/weitere-s-presso; accessed on August 3, 2017]

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017b): RiverCell – Konzipierung und Entwicklung einer Brennstoffzellen-Hybridanlage für ein Flussschiff (Kreuzfahrt- und Schubschiff) [www.now-gmbh.de/de/nationales-innovationsprogramm/projektfinder/stationaere-energieversorgung/rivercell; accessed on August 3, 2017]

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017c): Demonstrationsbetrieb BZ-Flurförderfahrzeuge Daimler Werk Düsseldorf [www.now-gmbh.de/en/national-innovation-programme/projektfinder/spezielle-maerkte/bz-flurfoerderfahrzeuge-daimler-werk-duesseldorf; accessed on August 3, 2017]

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017d): Callux-Praxistest mündet in Markteinführung [www.now-gmbh.de/content/2-nationales-innovationsprogramm/5-strom-und-waerme-mit-brennstoffzellen/1-callux/2015-11-26_callux_presse-info.pdf; accessed on August 3, 2017]

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (2017e): Leonardo II [www.now-gmbh.de/de/nationales-innovationsprogramm/projektfinder/stationaere-energieversorgung/leonardo-ii; accessed on August 3, 2017]

Next Kraftwerke GmbH (2017): Über uns [www.next-kraftwerke.de/unternehmen]

O

Öko-Institut e.V. (2016): Fragen und Antworten zu Obsoleszenz [www.oeko.de/oekodoc/2464/2016-003-de.pdf; accessed on March 19, 2017]

Organisation for Economic Co-operation and Development (2014): The Cost of Air Pollution. Health Impacts of Road Transport. Zusammenfassung in Deutsch [www.oecd-ilibrary.org/docserver/download/9789264210448-sum-de.pdf?expires=1489863434&id=id&accname=guest&checksum=399279855093E4966DF6D6288ADF173C; accessed on March 18, 2017]

P

Patrignani, N./ Kavathatzopoulos, I. (2016): Cloud computing: the ultimate step towards the virtual enterprise?, ACM SIGCAS Comput. Soc., Vo. 45, No. 3, page 68-72

Philips (2015): Philips provides Light as a Service to Schiphol Airport [www.philips.com/a-w/about/news/archive/standard/news/press/2015/20150416-Philips-provides-Light-as-a-Service-to-Schiphol-Airport.html; accessed on April 30, 2017

Piria, Raffaele/Naims, Henriette/Lorente Lafuente, Ana Maria (2016): Carbon Capture and Utilization (CCU): Klimapolitische Einordnung und innovationspolitische Bewertung. Berlin/Potsdam: adelphi, IASS [www.adelphi.de/de/publikation/carbon-capture-and-utilization-ccu-klimapolitische-einordnung-und-innovationspolitische; accessed on March 21, 2017]

Proff, Heike/Schönharting, Jörg/Schramm, Dieter/Ziegler, Jürgen (eds.) (2012): Zukünftige Entwicklungen in der Mobilität, Wiesbaden

Q

QNX Software Systems Limited (2017) [www.qnx.de/?lang=de; accessed on April 30, 2017]

QT Mobilitätsservice GmbH (2017): Wo immer du hin willst: Gehe deinen eigenen Weg. Über Qixxit [www.qixxit.de/ueberqixxit/; accessed on April 30, 2017]

R

Ramge, Thomas (2015): Disruption, Plattform, Netzwerkeffekt: Die drei Zauberworte, brandeins online [www.brandeins.de/archiv/2015/handel/disruption-plattform-netzwerkeffekt-die-drei-zauberworte-neue-wirtschaft/; accessed on April 30, 2017]

REN 21 Renewable Energy Policy Network for the 21st Century (2017): Renewables Global Status Report 2017 [www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf; accessed on July 31, 2017]

Roland Berger GmbH (eds.) (2016a): Digital factories, Think Act Content [www.rolandberger.com/de/Publications/pub_digital_factories.html; accessed on July 31, 2017]

Roland Berger GmbH (eds.) (2016b): Plan D – konsequent digital [www.rolandberger.com/de/press/Neue-Studie-Plan-D-%E2%80%93-konsequent-digital-2.html; accessed on July 31, 2017]

Roland Berger Strategy Consultants GmbH/Bundesverband der deutschen Industrie e. V. (eds.) (2015): Die digitale Transformation der Industrie [http://bdi.eu/media/user_upload/Digitale_Transformation.pdf; accessed on July 31, 2017]

S

Schalmo, Daniel et al. (eds.) (2017): Digitale Transformation von Geschäftsmodellen. Grundlagen, Instrumente und Best Practices, Wiesbaden

Schalmo, Daniel/Rusnjak, Andreas (2017): Roadmap zur digitalen Transformation von Geschäftsmodellen, in: Schalmo, Daniel et al. (eds.) (2017): Digitale Transformation von Geschäftsmodellen. Grundlagen, Instrumente und Best Practices, Wiesbaden, page 1-32

SERI Nachhaltigkeitsforschung und -kommunikations GmbH (2012): Nachhaltigkeit in Stadtplanung, Bauen und Wohnen [http://seri.at/allgemeines/2012/05/02/sustainability-in-urban-planning-construction-and-living/; accessed on April 2, 2016]

Statistisches Bundesamt (2017a): Nachhaltige Entwicklung in Deutschland. Indikatorenbericht 2016 [www.destatis.de/DE/Publikationen/Thematisch/UmweltoekonomischeGesamtrechnungen/Umweltindikatoren/IndikatorenPDF_0230001.pdf?__blob=publicationFile; accessed on March 18, 2017]

Statistisches Bundesamt (2017b) [www-genesis.destatis.de/genesis/online;jsessionid=E823FA0A450239F752C932D8AB5C3E69.tomcat_GO_1_1?operation=previous&levelindex=2&levelid=1490956256698&step=2; accessed on March 31, 2017]

Statistisches Bundesamt (2017c): Deutsche Exporte im Jahr 2016 um 1,1% gestiegen [www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Aussenhandel/GesamtentwicklungJahr.html; accessed on March 31, 2017]

Statistisches Bundesamt (2017d): Abfallbilanz 2014 [www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Umwelt/UmweltstatistischeErhebungen/Abfallwirtschaft/Tablen/TablenAbfallbilanzKurzuebersicht.html; accessed on April 15, 2017]

Statoil (2018): World's first floating wind farm has started production [www.statoil.com/en/news/worlds-first-floating-wind-farm-started-production.html; accessed on January 23, 2018]

U

Umweltbundesamt (2014): Rebound-Effekte [www.umweltbundesamt.de/themen/abfall-ressourcen/oekonomische-rechtliche-aspekte-der/rebound-effekte; accessed on April 30, 2017]

Umweltbundesamt (2015a): Kartierung des anthropogenen Lagers in Deutschland zur Optimierung der Sekundärrohstoffwirtschaft [www.umweltbundesamt.de/publikationen/kartierung-des-anthropogenen-lagers-in-deutschland; accessed on January 23, 2018]]

Umweltbundesamt (2015b): Ein Meer von Kunststoffen [www.umweltbundesamt.de/themen/wasser/gewaesser/meere/nutzung-belastungen/muell-im-meer; accessed on March 26, 2017]

Umweltbundesamt (2016a): Die Nutzung natürlicher Ressourcen. Bericht für Deutschland 2016, Dessau

Umweltbundesamt (2016b): Urban Mining [www.umweltbundesamt.de/themen/abfall-ressourcen/abfallwirtschaft/urban-mining; accessed on March 26, 2017]

Umweltbundesamt (eds.) (2016c): Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz" [www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_11_2016_einfluss_der_nutzungsdauer_von_produkten_obsoleszenz.pdf; accessed on March 19, 2017]

Umweltbundesamt (2016d): Elektrogeräte werden immer kürzer genutzt. press release dated February 15, 2016 [www.umweltbundesamt.de/presse/pressemitteilungen/elektrogeraete-werden-immer-kuerzer-genutzt; accessed on March 19, 2017]

Umweltbundesamt (2016e): Antibiotika: Tierhaltung und Humanmedizin können das Grundwasser belasten – press release dated June 14, 2016 [www.umweltbundesamt.de/presse/pressemitteilungen/antibiotika-tierhaltung-humanmedizin-koennen-das; accessed on March 25, 2017]

Umweltbundesamt (2016f): Rebound-Effekte. Empirische Ergebnisse und Handlungsstrategien [www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/rebound-effekte_empirische_ergebnisse_und_handlungsstrategien_hintergrundpapier.pdf; accessed on April 16, 2017]

Umweltbundesamt (2017a): Emissionen von direkten und indirekten Treibhausgasen und von Schwefeldioxid [www.umweltbundesamt.de/sites/default/files/medien/384/bilder/dateien/3_tab_emi-direkt-indirekt-thg_2017-03-17.pdf; accessed on November 23, 2017]

Umweltbundesamt (2017b): Abfallaufkommen [www.umweltbundesamt.de/daten/abfall-kreislaufwirtschaft/abfallaufkommen#textpart-7; accessed on March 14, 2017]

Umweltbundesamt (2017c): „Power to Gas/Power to Liquid“ als Zukunftstechnologien fördern [www.umweltbundesamt.de/themen/power-to-gas-power-to-liquid-als; accessed on March 19, 2017]

Umweltbundesamt (2017d): Emissionen des Verkehrs [www.umweltbundesamt.de/daten/verkehr/emissionen-des-verkehrs#textpart-1; accessed on August 1, 2017]

Umweltbundesamt (2017e): Treibhausgas-Emissionen in Deutschland [www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland; accessed on January 3, 2018]

Umweltbundesamt/Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (eds.) (2014): Wirtschaftsfaktor Umweltschutz. Produktion-Außenhandel-Forschung-Patente: Die Leistungen der Umweltschutzwirtschaft in Deutschland [www.umweltbundesamt.de/publikationen/wirtschaftsfaktor-umweltschutz-0; accessed on March 18, 2017]

Unattributed (2015): Obama: „Wendepunkt für die Welt“ – dank Amerika, süddeutsche.de dated December 13, 2015 [www.sueddeutsche.de/wissen/reaktionen-auf-klimavertrag-wir-haben-geschichte-geschrieben-1.2780271; accessed on April 8, 2017]

Unattributed (2016): Verkehrsminister Dobrindt: Selbstfahrende Autos erobern 2020 die deutschen Autobahnen, Frankfurter Allgemeine Zeitung, January 1, 2016

Unattributed (2017a): Hunderte amerikanische Firmen stellen sich gegen Trump, in: faz.net dated June 2, 2017 [www.faz.net/aktuell/wirtschaft/wirtschaftspolitik/rueckzug-aus-klimaabkommen-us-firmen-kritisieren-donald-trump-15043616.html; accessed on July 26, 2017]

Unattributed (2017b): Wal hatte 30 Plastiktüten im Magen [www.spiegel.de/wissenschaft/natur/muell-im-meer-wal-hatte-30-plastiktueten-im-magen-a-1132942.html; accessed on March 26, 2017]

UNESCO (2016): The United Nations World Water Development Report 2016. Water and Jobs [www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2016-water-and-jobs/; accessed on July 31, 2017]

UNESCO (2015): The United Nations World Water Development Report 2015. Water for a Sustainable World [http://unesdoc.unesco.org/images/0023/002318/231823E.pdf; accessed on July 31, 2017]

United Nations (2017a): press release dated June 1, 2017: Secretary-General Calls United States Decision to Withdraw from Paris Agreement on Climate Change ’Major Disappointment’ [www.un.org/press/en/2017/sgsm18548.doc.htm; accessed on July 26, 2017]

United Nations, Department of Economic and Social Affairs (2017): Sustainable Development Knowledge Platform [https://sustainabledevelopment.un.org/sdg6; accessed on March 14, 2017]

V

VAUDE (2017). [http://nachhaltigkeitsbericht.vaude.com/gri/produkte/greenshape-konzept.php; accessed on April 29, 2017]

Verband der Automobilindustrie (2017) [http://vda.de; accessed on April 30, 2017]

voxeljet AG (2015): 3D-Drucksysteme: Wirtschaftlichkeit inklusive [www.voxeljet.de/systems/; accessed on April 30, 2017]

W

Welthungerhilfe (2017a): Wasser ist ein Menschenrecht [www.welthungerhilfe.de/wasser-ist-menschenrecht.html; accessed on March 14, 2017]

Welthungerhilfe (2017b): Abwasser macht krank [www.welthungerhilfe.de/abwasser-macht-krank.html; accessed on March 14, 2017]

Willenbrock, Harald (2016): Die Auffanglösung [www.brandeins.de/archiv/2016/gesundheit/guppy-friend-alexander-nolte-oliver-spies/; accessed on August 17, 2017]

Wolter, Stefan (2012): Smart Mobility – Intelligente Vernetzung der Verkehrsangebote in Großstädten, in: Proff, Heike/Schönharting, Jörg/Schramm, Dieter/Ziegler, Jürgen (eds.) (2012): Zukünftige Entwicklungen in der Mobilität, Wiesbaden, page 527-548

Workaround GmbH (2017): ProGlove - wearables for industry [www.proglove.de/; accessed on April 30, 2017]
World Bank (2013): Global Waste on Pace to Triple by 2100 [www.worldbank.org/en/news/feature/2013/10/30/global-waste-on-pace-to-triple; accessed on March 18, 2017]

World Bank (2013): Global Waste on Pace to Triple by 2100 [www.worldbank.org/en/news/feature/2013/10/30/global-waste-on-pace-to-triple; accessed on March 18, 2017]

World Bank (2016): High and Dry. Climate Change, Water, and the Economy [www.worldbank.org/en/topic/water/publication/high-and-dry-climate-change-water-and-the-economy; accessed on July 31, 2017]

World Bank (2017) [http://databank.worldbank.org/data/download/GDP.pdf; accessed on January 23, 2018]

World Wildlife Fund (2017): Living Planet Report 2016 [www.wwf.de/living-planet-report/; accessed on March 15, 2017]

Z

ZAE Bayern (2017): Smart Grid Solar | Netzmanagement [www.smart-grid-solar.de/arbeitspakete/netzmanagement.html; accessed on April 30, 2017]

Index of abbreviations

BDL	Bundesverband der Deutschen Luftverkehrswirtschaft (German aviation industry association)
BIM	Building Information Modeling
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
bn	Billion
BRICS	Brazil, Russia, India, China and South Africa
CAGR	Compound annual growth rate
CCS	Carbon dioxide capture and storage
CCU	Carbon capture and utilization
CEP	Clean Energy Partnership
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP21	United Nations Framework Convention on Climate Change, 21^{st} Conference of the Parties
CPS	Cyber-physical system
CSR	Corporate social responsibility
DERA	Deutsche Rohstoffagentur (German Mineral Resources Agency)
DNA	Desoxyribonucleic acid
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (German Association for Water, Wastewater and Waste)
Eds.	Editors
EFB	Electronic Flight Bags
eFF	electronic Flight Folder
EMAS	Eco-Management and Audit Scheme
ERP	Enterprise resource planning
EU	European Union
EUR	Euro
G20	Group of Twenty
GDP	Gross domestic product
GHG	Greenhouse Gases
GWP	Global warming potential
H_2	Hydrogen
HPA	Hamburg Port Authority
HVAC	Heating, ventilation and air-conditioning
IASS	Institute for Advanced Sustainability Studies
ICT	Information and communication technology
IEA	International Energy Agency
NDC	Nationally Determined Contributions
IoT	Internet of Things
ISO	International Organization for Standardization
ITF	International Transport Forum
KfW	Kreditanstalt für Wiederaufbau (Germany-based promotional bank)

KGOE	Kilogram of oil equivalent
KIT	Karlsruhe Institute of Technology
KPI	Key performance indicators
KrWG	Kreislaufwirtschaftsgesetz (Waste Management and Recycling Act)
KrW-/AbfG	Kreislaufwirtschafts- und Abfallgesetz (Recycling and Waste Act)
kW	Kilowatt
LED	Light-emitting diodes
m	Million
M2M	Machine to machine
MBit	Megabit
Mbit/s	Megabit per second
MDG	Millennium Development Goals
NAPE	Nationaler Aktionsplan Energieeffizienz (National Action Plan on Energy Efficiency)
NFC	Near Field Communication
NIP	Nationales Innovationsprogramm Wasserstoff (National Innovation Program for Hydrogen and Fuel Cell Technology)
NOW	Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (National Organization for Hydrogen and Fuel-Cell Technology)
O_2	Oxygen
OECD	Organisation for Economic Co-operation and Development
OHSAS	Occupational Health and Safety Assessment Series
OLED	Organic light-emitting diodes
ProgRess	Deutsches Ressourceneffizienzprogramm (German Resource Efficiency Program)
P2G	Power to gas
PtG	Power to gas
PtL	Power to liquid
PV	Photovoltaics
R&D	Research & development
REN 21	Renewable Energy Policy Network for the 21st Century
SDG	Sustainable Development Goal
SME	Small and medium-sized enterprises
SOFC	Solid oxide fuel cell
TEU	Twenty-foot Equivalent Unit
TLP	Tension leg platform
TOE	Tonne(s) of oil equivalent
UBA	Umweltbundesamt (German Environment Agency)
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VCI	Verband der Chemischen Industrie (German chemical industry association)
VDA	Verband der Automobilindustrie (German automotive industry association)
WHO	World Health Organisation
WWF	World Wildlife Fund
ZAE	Bayerisches Zentrum für angewandte Energieforschung (Bavarian Center for Applied Energy Research)
ZSW	Zentrum für Sonnenenergie und Wasserstoff-Forschung (Center for Solar Energy and Hydrogen Research)

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