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Abstract

Digitization—the continuing convergence of the real and the virtual worlds will be the main driver of innovation and change in all sectors of our economy. The exponentially growing amount of data and the convergence of different affordable technologies that came along with the definite establishment of Information and Communication Technology are transforming all areas of the economy. In Germany, the Internet of Things, Data and Services plays a vital role in mastering the energy transformation, in developing a sustainable mobility and logistics sector, in providing enhanced health care and in securing a competitive position for the leading manufacturing industry. This article discusses the impact, challenges and opportunities of digitization and concludes with examples of recommended policy action. The two key instruments for enhanced value creation in the Age of Industrie 4.0 are platform-based cooperation and a dual innovation strategy.

The manufacturing industry is the backbone of the German economy, accounting for 22.4% of gross domestic product (GDP) and employing one sixth of Germany's total workforce [15]. By way of comparison, the manufacturing industry accounts for 11.9% of GDP in the US and just 10% in France and the UK [17]. The German industry continues to produce a huge trade surplus year after year. Indeed, the competitiveness of the German industry played a pivotal role in enabling the country to successfully overcome the recent

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financial and economic crises. Nevertheless, if Germany's manufacturing industry is to remain competitive and the country wishes to maintain its position as a leading manufacturing equipment supplier, then it will need to keep coming up with new innovations. In order for the German model to deliver lasting success, it requires a successful innovation system. If we wish to secure the future of Germany's manufacturing industry and preserve domestic production, then we must initiate and actively shape the next wave of innovation.

Digitization—i.e. the networking of people and things and the convergence of the real and virtual worlds that is enabled by information and communication technology (ICT)—will be the most powerful driver of innovation over the next few decades and will act as the trigger of the next wave of innovation. It will transform all key infrastructures in fields such as energy, mobility, healthcare and manufacturing [18]. As a result, today's value chains and business models will come under increasing pressure. Digitization is having a highly disruptive impact on markets, the world of work and our social structures. For example, will traditional automotive manufacturers be capable of making the leap required to produce smart, autonomous cars, or will the new key players come from the ICT industry? The German business newspaper *Handelsblatt* recently reported that Google has acquired seven specialist robotics companies and is now planning to start making robots [16]. One can only imagine the economic implications of this type of development, particularly for a country with a strong industrial core like Germany.

The process of digitization is already taking place at a rapid pace. There were 113 million new mobile subscriptions in the third quarter of 2013, with 30 million in China, 10 million in India, 6 million in Bangladesh, 5 million in Indonesia and 4 million in Egypt. By the end of September 2013, the total number of mobile users worldwide stood at approximately 4.5 billion. Over the past three years, the ratio of data to speech has risen from around 1:1–10:1. By 2020, it is estimated that 6.5 billion people and 18 billion objects will be connected to mobile networks [11]. The virtual world is thus clearly extending its reach into the physical environment. In a study carried out on behalf of the industry association BITKOM (Federal Association for Information Technology, Telecommunications and New Media), Fraunhofer ISI estimates that the economic benefit of digitization and increased real-world networking in the fields of energy, healthcare, transport, education and government is at a level of 56 billion euros a year [5].

It is thus clear that the impact of digitization in terms of transforming the world we live in will be comparable to past waves of innovation such as those triggered by mechanisation and electricity. Having slowly gathered momentum over the past few decades, the process of digitization has accelerated rapidly in recent years. Even though the technological developments themselves are more evolutionary in nature, their impact will be felt as a genuine revolution. The advantage we have is that we are able to see this “stealthy” or “perceived” revolution coming and can therefore analyze it and play an active role in shaping it. However, in order to do this, we first of all need to understand (1) the impact that digitization is having on Germany, (2) the areas where the first changes are already being experienced, (3) the opportunities and (4) the challenges that it poses for German industry and (5) the role played by the issue of acceptance. This will enable us to deter-

mine (6) how we can shape the economic, scientific, political and social changes triggered by digitization. From studying these questions, it will become clear that there are two key instruments that should be used to support this “stealthy revolution”: increased platform-based cooperation and dual innovation strategies.

2.1 The Internet of Things, Data and Services as the Driver of Innovation Over the Coming Decades

The next wave of innovation will be driven by the Internet of Things, Data and Services, an “*Internet of everything*” where subjects and objects alike can communicate in real time. The Internet of Things, Data and Services—i.e. the real-time networking of objects and subjects and in particular the convergence of the real and virtual worlds—has not come about as a result of a single, recent, disruptive innovation. In fact, the relevant technology has been developing continuously ever since the first electronic computers appeared at the end of the 1940s. Whilst this process began slowly, it is now gathering more and more momentum. Processing power, memory size and network capacity are all growing exponentially, while their cost is falling at a similar rate. Looking back, it is apparent that Moore’s Law, which states that computer processing power will double every one-and-a-half to two years, has in fact become a self-fulfilling prophecy [25].

However, it is not just the rate at which these performance parameters are developing that has given rise to the Internet of Things, Data and Services. Far more important is the convergence of various different affordable technologies (see Fig. 2.1) to create synergies that in turn lead to qualitatively different opportunities and impacts that ultimately come to be perceived as a revolution.

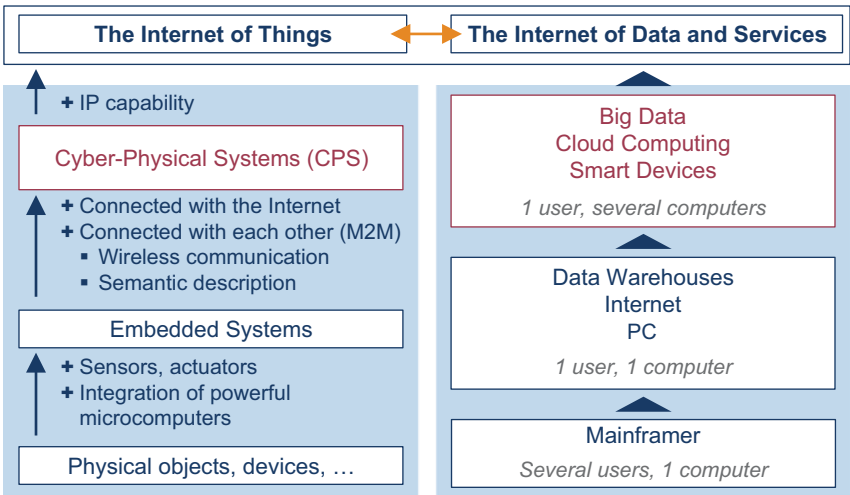


Fig. 2.1 Converging technological developments. (Source: own illustration)

The trend is based on embedded systems, i.e. powerful microcomputers that can be built into every conceivable type of object i.e. billions of powerful microcomputers owing to the exponential growth in IT performance parameters alluded to above. Thanks to the spread of RFID technology, embedded systems have now come to be regarded as a basic technology. At the same time, these embedded systems are now being equipped with sensors and actuators. The resulting systems are capable of recording, storing and processing a wide variety of data from their surroundings that can then be used to enable them to influence their environment. Their size and performance follow “laws” not dissimilar to those governing computers. These systems transform objects into smart objects and environments into smart environments. Even today, 98 % of all processors are not found in computers but are instead built into smart objects and increasingly into high-tech products. For example, a mid-range car will on average contain around 150 embedded systems.

At the same time, mobile communications and WLAN, together with the introduction of the IPv6 Internet protocol in 2012, have triggered a major expansion of the Internet. We now have more than enough IP addresses for our current needs. This means that it is easy for embedded systems to connect to each other and to the Internet whenever they like, exchange data and make their capabilities available as online services. The result is an “invisible ‘digital upgrading’ of traditional objects” [26]: the real and digital worlds converge and physical objects are enhanced with the flexible capabilities of digital functions, turning embedded systems into Cyber-Physical Systems [13]. These Cyber-Physical Systems gather a huge amount of data about their real environment and digital processes. Whereas in the past, data had to be recorded manually and then transferred to storage media, with all the errors that are inherent in this process, now it is possible to gather data automatically. Moreover, the continuing development of sensor technology is delivering higher and higher data resolution, enabling fine-grained monitoring of the environment.

In addition to the above, cloud computing makes affordable storage now available for the exponentially rising volume of data that is being generated by smart objects and subjects. The wealth of data stored in these “data factories”—commonly referred to as big data—can then be mined using smart algorithms based on correlations and probability calculations. The data is analysed and patterns are identified that generate information that can be correlated in order to produce new knowledge. Cloud computing thus provides the basis for developing innovative new services using the knowledge that has been obtained in this way. New service infrastructures are emerging that offer a comprehensive range of smart services for every area of our lives as well as business webs with SOA-based corporate software (service-oriented architecture) that supports end-to-end cross-company business processes and flexible business networks.

In the Internet of Things, Data and Services, any technological device can exchange information at high speeds with any other device or person anywhere in the world. Up-to-the-minute information about the status of individual devices and their surroundings can be retrieved at any time. Technology infrastructure can be monitored and operated even over huge physical distances. Networking enables simultaneous control and optimal coordination of a wide variety of complex technological processes.

As our society makes the transition towards sustainable energy, smart grids allow volatile energy sources to be incorporated by matching supply and demand in real time in a highly complex energy system. In the future, smart navigation systems on board cars, buses, trains and other vehicles will share information about traffic volumes, particulate levels and disruption to local public transport services, enabling traffic in the cities of tomorrow to be managed autonomously. It will also be possible to connect manufacturing systems and business processes in factories and businesses in real time and across different companies—from ordering up to outbound logistics. All of this will ultimately create the benefits for society and industry that are outlined in the following section.

2.2 Driving Innovation in Every Area of Our Lives

While the impact of the Internet of Things, Data and Services will undoubtedly be felt in every area of our lives, this chapter will focus specifically on the fields of energy, mobility and logistics, healthcare and manufacturing (see Fig. 2.2). If an object is described as “smart”, this means that its technology is based on embedded systems, sensors, Cyber-Physical Systems, cloud computing and big data: “IT is everywhere—the vision of ubiquitous computing has become reality” [13]. The potential of the Internet of Things, Data and Services becomes particularly apparent when different, formerly separate fields of application converge with each other. In the future, these different fields will have new relationships, interdependencies and interactions with each other. For example, it is impossible to realize a smart factory unless the relevant logistics processes are also “smart”,

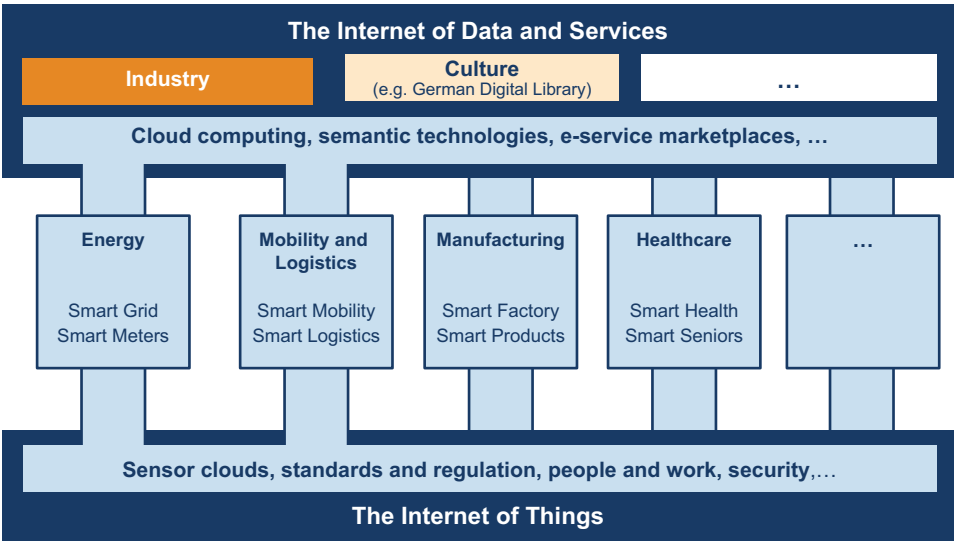


Fig. 2.2 The Internet of Things, Data and Services. (Source: own illustration)

while the reverse is also true: “These interactions will be so extensive that a lack of certain developments in one scenario could result in neighbouring scenarios being unable to create the conditions needed for them to maximise their potential” [13].

2.2.1 An ICT-based Energy System

Germany has embarked upon an ‘energy transition’, setting itself the goal of phasing out nuclear power by 2022. And despite this nuclear phase-out, it has also committed to a 40% cut in its greenhouse gas emissions (compared to 1990 levels) by 2020, rising to at least 80% by 2050. At the same time, it has pledged to increase the percentage of solar and wind power and other forms of renewable energy in its electricity mix from the current figure of 17% to at least 35% by 2020 and 80% by 2050 [14].

This fundamental transformation of Germany’s energy supply will trigger major changes in the structure of the energy supply system over the coming decades. There will be a rise in the number of small, decentralized producers providing a highly volatile supply of electricity that is heavily dependent on weather conditions. These changes on the supply side will be accompanied by changes in consumer behavior. Electric mobility, heat pumps and other types of consumption will transform the demands on the distribution grid. It will therefore be important to ensure their smart integration into the system. All of this will pose huge challenges for policymakers, industry, the research community and the public. In short, there will be an unprecedented increase in the complexity of our energy system that we would be unable to manage using today’s methods. Digitization and the potential offered by smart networking nonetheless hold out the prospect of allowing us to meet these challenges and will thus constitute the cornerstone of our future energy systems.

Smart grids respond in real time to calm wind conditions or high levels of solar radiation and incorporate both industrial generating facilities and private consumers. By combining energy technology and ICT, they enable measurement, control and automation to be performed at a high time resolution across the entire distribution grid. Furthermore, the widespread deployment of ICT allows new distribution and business models to be implemented that provide consumers with incentives to change their energy consumption patterns. The result is an Internet of Energy where electricity producers, storage facilities and consumers coordinate and optimize their processes in an independent and automated manner.

In principle, there is nothing to prevent the rollout and expansion of smart grids. However, failure to implement an integrated overall strategy that coordinates all of the key areas where action is required could set the energy transition back by several years or in the worst-case scenario even cause it to fail completely [4]. Smart grids are not just an optional extra but an absolute necessity. Today’s electricity infrastructure is simply not designed to cope with the volatile supply of electricity from renewable energy sources such as wind and solar power that increasingly will need to be incorporated into the grid in the future.

The complexity of the energy transition can thus be addressed through the digitization and integration of the energy system to create an Internet of Energy. However, this will require realistic migration paths and optimal integration of existing infrastructure. If the energy transition is to succeed, it will be necessary to find the right mix of technological, social and business model innovations. The complexity of systems is constantly increasing and this also applies to our energy supply. In order to take full advantage of the opportunities provided by digitization in the field of energy and to ensure that it serves the energy policy goals of Germany's energy transition, it will be necessary to guarantee both coordinated cooperation between all the relevant actors and stringent monitoring (see also Sect. 2.3).

2.2.2 Sustainable Mobility and Logistics—Smart Networking

Logistics acts as the main artery of our economy. Efficient logistics networks are keys to securing economic growth and enabling Germany's export trade to do business on the global market. The German logistics industry is worth 222 billion euros and employs 2.8 million people, making it the country's third largest industry [3]. Digitization is transforming logistics into a high-tech industry, as well as enabling environmentally friendly and affordable individual mobility.

The key physical enabler of mobility and trade is efficient transport. This is an absolutely indispensable requirement, since in the Age of Industrie 4.0 (see Sect. 2.2.4), mobility and logistics needs are set to grow rather than fall. The volume of private and freight traffic in Germany has been rising for many years. In Germany alone, it is estimated that private car traffic will grow by 20 % and heavy goods vehicle traffic by 34 % by 2020 [24]. The causes of this increase include trends such as urbanization and the growth in global trade. Moreover, the rapid growth in e-commerce has led to a sharp increase in transport requirements for delivering goods to private households. This poses a series of new challenges for the logistics industry.

At the same time, dwindling natural resources and the need for energy efficiency and climate protection all mean that modern freight and passenger transport must comply with a different set of requirements than in the past. Mobility and logistics services and transport infrastructure need to match up to the demands placed on them by society. Today's users judge these services based on their quality and reliability—even when the infrastructure is overloaded or affected by disruption—as well as their efficiency, sustainability and environmental and land use impact.

In this area, too, digitization will be a key enabler of a reliable and sustainable future transport system and supply of goods. The principles of the Internet of Things, Data and Services are one of the keys to achieve efficiency in the delivery of individual orders, supplier relationships and mobility service provision. Indeed, it is essential for real-time logistics networking to be developed as an integral part of the Industrie 4.0 initiative. For example, if supply chains are to be networked with manufacturing facilities in real time

so that production can respond instantaneously to supply variability, this will require the integration of manufacturing and logistics via the Internet of Things—in other words, the digitization of logistics. More and more “smart logistics” and “smart mobility” systems are thus emerging, comprising networks of several small-scale entities. These enable efficient and reliable organization of transport between different locations (“door-to-door transport”) and throughout the entire life cycle of goods (production-transport-storage-consumption-disposal). For example, the Effizienzcluster LogistikRuhr has been running a joint project for the past three years called smaRTI (smart reusable transport items)¹ to work on concrete solutions for smart material flows. The goal is to use cloud-based data services to enable real-time tracking of load carriers in order to speed up processes, reduce waiting times and cut out unnecessary costs. Smart load carriers bearing RFID transponders and bar codes were first employed to enable optimization of distribution processes across different companies and even different sectors in the retail trade, where they delivered a two percent increase in turnover worth eight billion euros. Plans are already afoot for applications outside of the retail trade.

The shift away from centrally controlled processes towards decentralized structures and decentralised processes that are adapted to these structures is making it possible to manage increasingly large and complex systems in logistics and especially in the field of private and freight transport. In order to deliver more efficient logistics and mobility, these need to be combined with new, resource-efficient transport technologies such as electric mobility and semi-autonomous urban transport systems. Other strategies include shared use of transport and logistics infrastructure (e.g. transshipment facilities, delivery journeys and goods collection systems) by businesses and service providers, as well as more effective traffic management. All of this requires both operational networking of everyone involved at the process level and collaborative business processes via the Internet.

It is also necessary to make logistics and transport systems more robust so that they are better able to cope with disruption, and to increase their medium to long-term adaptability. Real-time systems capable of recording events and status using Auto-ID and sensor technology will allow early detection and location of any disruption to the system, thereby enabling a rapid response.

Increased mobility also generates more traffic, resulting in higher levels of congestion and noise and air pollution. We will therefore need new mobility concepts and products capable of meeting society’s requirements with regard to environmental protection, efficiency, and the quality of our towns and living spaces. It will no longer simply be a case of optimizing logistics in terms of costs—eco-efficiency and adaptability will be equally important goals. However, this vision will not be realized of its own accord. The logistics trade still doesn’t properly regard itself as a high-tech industry and nowhere near enough attention is currently being paid to logistics as a key R&D theme. Immediate action is needed to ensure that the logistics industry and the relevant research projects and training courses are equipped to meet the requirements of the age of digitization. It is essential to

¹ More information about the project is available at: <http://www.smart-rti.de/>.

develop competencies with regard to the practical use of the Internet of Things in the field of logistics: “With the advent of the fourth industrial revolution, it is becoming apparent just how profoundly logistics impacts upon the value-added processes of production, trade and services” [28].

Smart networking is also a key to electric mobility—and its role goes far beyond simply providing apps to help people find the nearest charging point. Smart cars will operate as nodes on the Internet, thus being connected to smart transport systems and smart grids as part of the Internet of Things, Data and Services. In the longer term, it will be possible to use the electric cars in this system for storing electricity, thereby making a significant contribution to the energy transition. The vehicles that we use for transport purposes will thus become a cornerstone of our energy system.

Electric mobility thus constitutes a model example of the application fields addressed in this chapter. In this domain, too, it is necessary to define and develop the right interfaces between the systems in order to enable migration towards smart infrastructures. And once again it will be essential to ensure cooperation between actors who previously had nothing to do with each other. In fact, this last aspect cuts across all the fields of application described in this chapter.

2.2.3 Personalized Medicine

In the field of healthcare, digitization and knowledge-based systems will have a lasting impact not only on the healthcare system itself but also on people’s lives. It will be essential to leverage the potential of e-health, among other things, in order to address the spiralling costs that threaten to accompany demographic change. The two priority goals in this area are prevention and personalization. The results of an expert survey conducted this year as part of the Innovation Dialogue coordinated by acatech emphatically confirmed that personalized medicine in particular is considered to have huge innovation potential. By sequencing the genome of individual patients, it will become possible to develop personalized treatments. In the future, individual patient records will not only contain details of their genetic make-up but will also include a wide range of physiological parameters. If this data is to generate useful pre-clinical and clinical information, it will be necessary to combine the relevant algorithms with clinical expertise in order to transform big data into smart data that can serve as the basis for new, knowledge-based services. In the future, personalized medicine will become the norm in our hospitals and GP practices. However, it will also conquer new domains outside the traditional healthcare system where the focus is on patients taking responsibility for their own healthcare. This so-called “third place” describes healthcare outside of hospitals or medical practices where patients take care of themselves with the aid of a burgeoning range of digital services [12]. This approach is set to become increasingly important and can help deliver substantial cost savings for our healthcare system. The experts interviewed in the survey believed that we will see new interactions between the various stakeholders involved in healthcare, with influence shifting

away from healthcare professionals and manufacturers and towards patients and payers. The entire life sciences field is going to require new business models where digitization plays a key role. Non-traditional actors such as Internet and telecommunication providers will enter the healthcare market. The Internet of Things, Data and Services will provide doctors and increasingly also patients with information about their personal health and offer assistance with the selection of treatment options. Moreover, it will help to bring about a change in behavior by creating incentives for effective prevention and treatment of diseases.

2.2.4 Industrie 4.0—The Internet of Things and Services in the Manufacturing Environment

Digitization is also triggering a radical transformation of the manufacturing environment. With the advent of the Internet of Things, Data and Services, we now stand on the verge of the fourth industrial revolution—Industrie 4.0 (see Fig. 2.3; [21]). The first stage of industrialization was ushered in by the invention of the steam engine at the end of the eighteenth century. Towards the end of the nineteenth century, this was followed by the introduction of electrical power and production lines, enabling the mass production of goods based on the division of labor. The subsequent stages are interpreted differently on either side of the Atlantic. Jeremy Rifkin [19] is among those who are currently proclaiming a third industrial revolution characterized by the use of renewable energy and the greening of production. However, it is equally true that we are already in the throes of a third, IT-based industrial revolution that started during the mid-1970s and has continued right up to the present day. This third revolution is characterized by the use of electronics and IT to drive automation of manufacturing processes, as machines take over part of the “brain-work” involved in production. This digital enhancement of proven concepts has undoubtedly delivered a quantum leap in productivity. However, the digitization of manufacturing continues its onward march and is now starting to take on a new quality. It is characterized by highly flexible control of production and associated areas via Cyber-Physical Systems that are networked in real time and are now replacing centrally controlled Computer-Integrated Manufacturing. In view of the timescale involved, many experts prefer to speak of evolution rather than revolution. However, the impact of Industrie 4.0 on economic development and work organization will be just as profound as the previous revolutions that also took several decades rather than just a few years for their full effect to be felt. As such, there will be a shift from competition between individual companies to competition between corporate networks, resulting in increased collaboration between businesses [2, 8].

Germany has one of the most competitive manufacturing industries in the world and is also a leading manufacturing equipment supplier. This is due to its ability to manage complex industrial processes where different tasks are performed by different partners in different geographical locations. It has been successfully employing ICT to do this for

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