ANALYSIS OF ENVIRONMENTAL POTENTIAL BY IMPLEMENTING INDUSTRY 4.0

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Abstract: *Due to volatile and fast moving markets, increasing competition or more complex product solutions, industrial companies are facing increasingly intricate challenges. High energy consumption, emissions output, resource scarcity and waste are just some of the issues enterprises have to manage. Industry 4.0 focuses on an intelligent and interconnected world in which smart factories represent the connection between digital and physical production networks. This interconnection can lead to a variety of environmental benefits, such as consuming fewer resources by means of intelligent connectivity of objects. The energy consumption of a company can be reduced by using start-stop technologies or big data transparency concerning resource and energy consumption to reach optimization potential in production.*

Keywords: Industry 4.0, environmental potentials, resources, energy

1. Introduction

While Industry 4.0 (I4.0) is increasingly discussed in theory and practice, the impact on the environment has only been investigated rudimentary. We try to close this gap, therefore, the main objective of this paper is to analyze environmental potentials that can result from the implementation of I4.0. To fulfill this objective, I4.0 in general and its main components are explained at the beginning. Afterwards, the environmental impacts of I4.0 are discussed with a special focus on resource and energy efficiency as well as recycling potential. This theoretical work builds the foundation for the development of an interview guide which is used subsequently for an empirical study in the form of expert interviews. As an outcome, the theoretical and empirical results will be interconnected and build the basis for the identification of environmental potentials that arise through the implementation of I4.0 and thus counteract environmental problems. Finally, a conclusion and further limitations will be discussed at the end of the paper.

2. The fourth industrial (R)evolution - Industry 4.0

"Industry 4.0 is in the way it is introduced, evolutionarily. […] we cannot demolish the factories and do everything quite differently. But the impact will be enormous, which is revolutionary." (Kagermann 2013, p.48)

The major idea of Industry 4.0 is the introduction of internet technologies into industry. Currently, industrial production is facing serious challenges, because information and communication technologies – e.g. the Internet of Things (IoT), Cyber-Physical Systems (CPS), Embedded Systems (ES), Augmented Reality (AR), Machine-to-Machine Communication (M2M), Cloud Computing − are entering the factory (Spieler 2016). I4.0 is a generic term, a vision that shows where the journey in industrial production is going. Many companies have already embarked unconsciously on this trip by using individual components of industry; for other companies, the concept is unchartered territory.

"Industry 4.0 describes the integration of modern Information and Communication Technologies (ICT) with traditional physical products and processes, which will create new business models and new markets." (Sihn 2015)

A short flashback: Industrialization began at the end of the 18th century with the introduction of mechanical production equipment, such as the mechanical loom for goods manufacturing. This first industrial revolution was followed by a second one at the end of the 19th century with the advent of electrically powered machinery used for mass production based on the division of work. The third industrial revolution started in the early 1970s. It was based on the use of electronics and information technologies to automate production processes. In conjunction with constant miniaturization and the unstoppable advance of the internet, ubiquitous computing has become reality. Microcomputers (embedded systems) are increasingly connected with each other and with the internet. These results in the convergence of the physical world and the virtual world (cyber world) to so-called Cyber-Physical Systems (CPS); the enabler of the fourth industrial revolution. CPS represent the further evolutionary stage from existing embedded systems and build the basis of an internet of things, which combines with the internet of services. The Internet of Things – the next generation of the internet – is a global system of IP-connected computer networks, sensors, actuators, machines and devices. Merging this physical world with the virtual world of the internet and software enables companies and consumers to create and enjoy new services that are founded on web-based business models. This will have a big impact on the way we do business (Lee 2008; Ashton 2009; Geisberger/Broy 2012; Kagermann et al. 2013; Bosch 2014; Heng 2014).

3. Smart Factory

Industry 4.0 focuses on smart products, procedures and processes in a *Smart Factory* as shown in figure 1. There is direct communication between people, machines, conveying and storage systems as well as production facilities, together bringing fast growing production complexity under control. Smart products know their manufacturing steps and future applications. With this knowledge, they actively support the production process and the documentation *("when was I produced, which parameters should be used to produce me, where should I be delivered to?").* I4.0 represents a paradigm change from "centralized" to "decentralized" production – made possible by technological progress, which constitute a reversal of conventional production process logic. This means, that industrial production machinery no longer simply "processes" the product; the product communicates with the machinery to tell it what to do (MacDougall 2014; Kagermann et al. 2013).

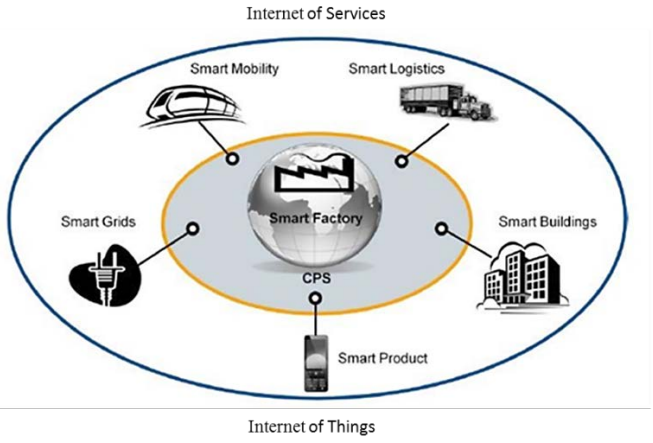

Fig. 1: *Smart Factory (Kagermann 2014, p.606).*

With its interfaces to smart mobility, smart logistics, smart buildings and smart grids, the smart factory is an important element

of future smart infrastructures. Conventional value chains will be refined and new business models will become established (Kagermann 2013; Heng 2014; Pessl et al. 2014). In the past, industrial revolutions led to a growing affluence. They also typically have had comprehensive social and environmental consequences – both positive and negative. Therefore, the next chapter examines the ecological impacts of Industry 4.0.

4. Industry 4.0 and its impact on ecological sustainability

To determine the impact of Industry 4.0 to the environment it is required to introduce sustainability in general at the beginning. In the literature there are different definitions of *sustainability*. The most famous and widespread known is the definition of the Brundtland commission within their report "our common future": *"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs […] it contains within two key concepts: the concept of „needs", in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations and social organization on the environment's ability to meet present and future needs."* (Brundtland 1987, p.41). Within the report sustainability is viewed from an ecological, an economic and a social perspective, also known as *the three pillars of sustainability*. These pillars are considered to be an equitable entity. The *ecological dimension of sustainability* aims to maintain the ecological system which provides a livelihood for mankind. This system absorbs emissions caused by man and provides natural resources that man needs for sustaining life. For companies this means, that all courses of action have an impact on the ecological system (Burschel et al. 2004). The main aim of the *social dimension of sustainability* is the maintenance of social compatibility. This means, that people in their daily action take care of others. Social compatibility includes different perspectives like the working and private world of people, preservation of lifestyles, social and political situations etc. Ultimately, however, every individual strives for a self-determined control of life. For companies this means e.g. that they must give their employees the opportunity to carry out a satisfactory activity (Mathieu 2002; Corsten/Roth 2012). The final *economical dimension of sustainability* aims to achieve and sustain a certain quality of life. For companies this means e.g. that they should rethink their current production and manufacturing techniques and consider sustainable alternatives. Furthermore, companies can use economic sustainability as a key indicator to support business planning (Brommer 2016).

In principle, all three dimensions of sustainability are equally important. As the problem areas of the ecological dimension of sustainability can have serious consequences for manufacturing industry (e.g. scarcity of resources, laws concerning pollutant emissions), this paper focuses on this dimension.

Production places a strain on the environment in many ways. In addition to the desired value added, a number of undesirable side effects (e.g. consumption of natural resources, energy consumption, emissions, waste etc.) are generated, which can lead to environmental damage. In Europe, there have been attempts for several years to limit these negative effects, which represents a major challenge for industry. Adherence to high environmental standards, emission trading scheme, CO2 reduction targets or raw material and energy price trends are just a few examples that increasingly influence the competitiveness of manufacturing companies. A high raw material and energy consumption within industrial manufacturing or increasing recycling requirements results not only in high costs, but entails also growing environmental and supply risks (Gabriel/Pessl 2015). One way to counter these problems could be Industry 4.0. The main objective of I4.0 is to strengthen and expand the long-term competitiveness of the company by heightening flexibility and efficiency of the production through communication, information and intelligence. These changes in production can also bring benefits to the environment. Thus, it offers an opportunity to make the production of the future ecologically sustainable. For example, through an intelligent connection of individual objects a resource-friendly production can be achieved or the energy consumption of the whole company can be reduced through automatic start-stop systems. The use of Big Data can lead to transparency in terms of resources and energy consumption in production.

Although principally many ecological advantages can be achieved through I4.0, this paper focuses on the main areas: resources, energy and recycling.

4.1 Resources

The digitization of production networks and processes has many advantages. For example, an improvement in quality management or process standardization can be achieved. Companies have greater transparency in planning and utilization of their plants, therefore, productivity achievements through digitization can be gained. In addition, the reject rate or the number of machine stops in production can be reduced (Busch et al. 2015). Another option to save scarce resources is 3D printing. A major advantage of this manufacturing technology is its recyclability, for example plastic waste can be recycled to raw material and reused for 3D printing. Furthermore, this technology makes it possible to extend the life cycle of components because of the lightweight design. In addition, a lower energy requirement during the use of the product can be achieved. Companies can produce spare parts by themselves at low cost and reduce their logistics costs (for transport, storage, etc.) (Bergius 2015; Petschow et al. 2014).

4.2 Energy

Industry 4.0 facilitates greater transparency in the energy system of a company, with all the sinks, sources and consumption peaks. It is possible for companies to implement intelligent energy management, where different elements of the company (the production, the lighting, the heating system, etc.) becoming part of a smart grid. Smart grids help the company to understand how its energy consumption is composed. This allows to analyze the efficiency and performance of the plants, and supports the optimization of affected plants or processes. This can reduce the energy costs and extend the life cycle of used devices (Jasperneite/Bretschneider 2013). A key technology to increase the energy efficiency of companies is the Smart Meter. It measures the energy consumption of plants, factories, houses, etc. in very short intervals. Thanks to the Smart Meter it is no longer necessary to read energy consumption on-site. It is connected to a network operator; to whom it automatically transfers the data (E-Control 2016).

4.3 Recycling

Recycling is the key for successfully implementing Industry 4.0 in production. If companies are able to set up their production in circles in the future, a large amount of materials and energy can be recovered. Experts are convinced that by I4.0 e.g. a global saving potential of 500 billion euros per year in the area of the food and packaging industry can arise. Energy and resource requirements can be cut by up to 25% (Duerand 2016). By networking machines, components and products are interconnected in real time. New and innovative solutions can develop, which will make it possible to extract even more raw materials (such as metals) from components and thus return them to the cycle. Well-functioning recycling networks are the key to unlocking such potential (Fraunhofer Institute Umsicht 2015).

5. Methodology

After the theoretical analysis of Industry 4.0 and its impact on sustainability, a qualitative research will be conducted, since the analysis of the potentials requires subjective opinions of persons to make qualitative statements. For this purpose, expert interviews

based on interview guidelines serve as a basis to discuss connections between I4.0 and environmental problems. Four experts from different manufacturing companies and different industries (electronics, logistics, automotive, IT) were selected. After the interviews, which were documented on tape, a transcript was written. An initial analysis has been done in accordance with the interview guideline, providing the foundation for further analysis. Afterwards, a qualitative content analysis (according to Mayring) was carried out in order to analyze the potential, based on the expert interviews (Mayring 2002). The qualitative content analysis is a systematic text approach, where rules are set up to evaluate texts for a research objective. A system of categories is to be developed in order to properly conduct the text analysis.

6. Results

The following section presents the results of the qualitative content analysis. For this, the transcripts of the expert interviews were used as a basis and analyzed using the coding guide. The results are divided into the categories: energy, resources and recycling (Spieler 2016).

6.1 Resources

The literature gives few examples of how Industry 4.0 can influence the ecological performance of a company. Due to the real-time data generation, companies are able not only to optimize their processes but also to become more flexible. I4.0 also enables companies to minimize their stocks and lead time. Furthermore, by using I4.0 technologies, companies can achieve greater resource efficiency. This increasing efficiency includes materials (e.g. higher output with the same quantity of material input), as well as machines and employees. By networking it is possible to network machines and production systems with each other and to achieve optimum utilization of the machines on-site. This increases the flexibility, cuts transportation costs and thus generates less pollution. With new IT technologies, it is possible to communicate more efficiently with colleagues or customers across continents. Another great potential is the ability to integrate IT systems, enabling bi-directional communication between companies. This can lead to a saving of resources, since, for example, maintenance intervals are passed on automatically and carried out (remote) by internet. Furthermore, this transparency enables e.g. a minimized reject rate or a reduction of machine downtimes. In summary, the potentials for resources area are shown in the following table.

Table 1: *Potential in the resource sector*

Potential	Impact
Resource efficiency	More output with the same input
Resource efficiency - material	Material costs are reduced
Resource efficiency - machines	Machine utilization on-site; less ecological footprint
IT technologies such as AR, M2M communication or Internet of Things	Efficient collaboration between companies and machines

6.2 Energy

In the energy sector, the use of I4.0 technologies can also create potentials for companies. For example, I4.0 concepts may help minimize power peaks and, as a result, let companies avoid high electricity costs. In addition, electricity consumption could be reduced to a certain extent in a large area, hence lowering the number of power stations, which could have a significant ecological impact. Furthermore, by using I4.0 technologies, energy management systems can be introduced more easily. Such systems enable companies to improve transparency and reduce unnecessary consumption. It is also possible to improve energy efficiency, therefore, a smaller ecological footprint is produced with the same output. An additional aspect is the power of customers and legislation, which are key drivers in the energy sector. They can ensure that companies focus their attention on I4.0 technologies. Another potential is the reduction of business trips and shipping volumes, which would again reduce the company's ecological footprint. In summary, the potentials in the energy sector are presented in the following table.

Table 2: *Potential in the energy sector*

Potential	Impact
Reduction of power peaks	Lower power costs, fewer power stations
Introduction of energy management systems	Higher transparency
Increase of energy efficiency	Reduced ecological footprint
Market & laws as a driving force	Increased use of I4.0 technologies
High degree of crosslinking	Fewer business trips and lower shipping volumes

6.3 Recycling

I4.0 technologies enable companies to reduce waste (e.g. through waste optimization) and make waste management more efficient. For example, in future it will be possible to measure the quantities in waste containers and to empty them only once they have actually reached a certain capacity. Also, I4.0 technology can help optimize waste management transport processes. Another great potential in terms of a diminished environmental impact lies in improving corporate image. However, this is only an advantage if customers are willing to pay a higher price for the ecologically more sustainable product. In summary the other ecological potentials of I4.0 are listed in the following table.

Table 2: *Recycling Potential*

Potential	Impact
Optimization of waste management	Less waste & scrap, Optimized transport routes

7. Summary and Outlook

The research of literature has shown, that I4.0 technologies have some potential for manufacturing companies. Optimal control of processes, machines, and resources can be achieved by real-time data collection. This makes it possible to react flexibly to any changes. Real-time data enables companies to minimize inventory and resources can be handled more efficiently. Furthermore, I4.0 facilitates more efficient energy management, allowing peak power or power consumption to be measured automatically by using Smart Meters. An enterprise can vastly improve business results with greater energy transparency. Additionally, through the use of I4.0 recycling capacity can improve significantly. Embedded systems can be installed in the smallest components and thus store information. This heightens the degree of recyclability, as companies have a knowledge how components can be used differently at the end of their life cycle. In addition, it is possible to implement efficient recycling strategies such as up-cycling to ensure that components will be efficiently processed. Additionally, new technologies such as 3D printing generate less waste, and companies can manufacture spare parts at a lower cost.

In addition to theoretical research, an empirical study was carried out in order to expand and/or substantiate the findings. For this purpose, expert interviews were used as a qualitative research method. The results of the interviews were analyzed using the qualitative content analysis by Mayring. For the empirical study, four experts from different industries (electronics, logistics, automotive, IT) were interviewed. In the course of analyzing the empirical study, the results of the literature research were confirmed. Furthermore, other potentials, which are not mentioned in the literature, were also identified. For example, companies can use I4.0 technology to reduce energy or electricity costs to a minimum, as embedding in the smart grid ensures optimal supply at the required times.

Another potential within the fourth industrial revolution is the driving force behind the market and legislation, as they can force companies to deal with I4.0 technologies to protect the environment. Thanks to the high degree of networking between

machines, people and company locations, it is possible to reduce business trips to a minimum and thus contribute to the protection of the environment.

The literature research and the empirical study show that different potentials can be achieved through I4.0 technologies. Nevertheless, it's important to note, that for the interviewed expert's, ecological problems alone are not a powerful reason for companies to implement technology concepts such as I4.0. This is due to high investment sums that are necessary.

Finally, we assume that ecological issues will play an increasingly important role in the future and that companies will have to find ways to deal with them. This can be done in different ways. It is essential that new technology concepts such as I4.0 are not to be ignored, as these will safeguard competitiveness and the environmental protection in the future. Industry 4.0 is not a product, which is implemented in a company. It is a process that is still in its early stages, but the technological components have been around for years. For this reason, there is considerable potential to increase industrial productivity. The missing factor here is the attitude of companies to devote themselves to the technological concept, in order to become more efficient not only on an economic but also on a sustainable level. Sustainability will continue to be an unavoidable factor in the future to drive corporate growth and ultimately protect the environment.

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