MSc Program
Environmental Technology & International Affairs

Industry 4.0 and its Effects on the Environment

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Dipl.-Ing. Dr. Klaus Rapp

David Thomas Uecker

1151983

Vienna, 01.06.2018

CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

Affidavit

I, **DAVID THOMAS UECKER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "INDUSTRY 4.0 AND ITS EFFECTS ON THE ENVIRONMENT", 51 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 01.06.2018

Signature

Abstract

This master thesis focus on the concept of Industry 4.0 and its potential nexus to the environment. The research questions wants to elaborate what the most prominent positive as well as negative changes concerning the environment that Industry 4.0 entails are. In order to answer this question, the existing pertinent literature has been searched and relevant findings have been inserted into this thesis. In order to not only rely on already existing research, two interviews with renowned experts have been conducted as an additional source of information. When combining all of the findings, the result is that the changes coming with Industry 4.0 will have positive as well as negative effects on the environment. The increase in demand for energy can be named as a potential negative effect on the environment, while the conservation and reduction in use of resources can be stated as a positive effect. Due to the early stage of implementation of Industry 4.0, hardly any hard facts and mostly forecasts and expectations were used as the base for the assumptions made.

Keywords: Industry 4.0, Environment, Sustainability

List of Abbreviations

Artificial intelligence = AI

Austrian Institute of Technology = AIT

Best Available Technology = BAT

Boston Consulting Group = BCG

B2B = business-to-business

Carbon Dioxide = CO_2

Circular Economy = CE

Cyber Physical System = CPS

European Union = EU

Industry 4.0 = I 4.0

Internet of Things = IoT

Information Technology = IT

Land use, land-use change and forestry = LULUCF

Nitrogen Oxide = NOx

Particulate Matter smaller than 2.5 micrometer = $PM_{2.5}$

Photo Voltaic = PV

Pricewaterhouse Cooper = PwC

Sulphur Dioxide = SO_2

Sustainable Development Goals = SDG

Sustainable Manufacturing = SM

Acknowledgements

First and foremost, I have to thank my parents, Thomas and Ursula, for their love and support throughout my life. Thank you for giving me the opportunity to follow my interests and to receive a high-quality education. Your moral as well as financial support allowed me to experience some very delightful and eventful years, for which I am eternally grateful!

I would like to express my sincere gratitude to my supervisor Dipl.-Ing. Dr. Klaus Rapp for his guidance and support. In particular the continuous advice and the straightforward communication made it possible to not only finish in time, but to compose a master thesis that I can be proud of. I could not have imagined having a better advisor and supervisor for my master thesis.

Besides my supervisor, I would like to thank Prof. Puxbaum and the administration of ETIA for always caring about us. Furthermore, I want to thank all of my colleagues of ETIA10 for the past two years. It was a great time and I am happy to have met you all.

A special thanks goes to my friends. It is the best feeling imaginable to know that your closest friends have your back no matter what. Sharing all those memories and experiences with you was a real pleasure. I really appreciate it!

Table of Contents

1. Introduction

As the title “Industry 4.0 and its Effects on the Environment” already discloses, is the intention of this master thesis to elaborate potential interconnections between the emerging concept of Industry 4.0 and the environment. The research question that guides the thesis reads as follows “What are the most prominent positive as well as negative changes concerning the environment that Industry 4.0 entails?”. In order to find scientifically based answers to this question, the various chapter of this master thesis focus on different aspects that are all required to construct a satisfying answer.

The chapter with the title “Industry 4.0” focuses on the concept of Industry 4.0 in general and provides information on the different technologies and sectors of interest. It covers the historic development of industrial revolutions, describes the current situation and why a the next step in industrial revolutions is due, states the origin and emergence of the concept of Industry 4.0 and provides detailed information on the various technological developments and changes such as digitalization, big data, etc. that refer to Industry 4.0.

As the tile “Industry 4.0 and the Environment” already indicates, does the focus of this chapter lie on the environment and its nexus with Industry 4.0. It covers aspects such as the definition of sustainability, which is a necessary prerequisite for the endeavor of this master thesis. Furthermore, it lists the key elements in approaching sustainability in manufacturing and states the most prominent benefits as well as challenges concerning the environment that an implementation of Industry 4.0 entails.

This chapter, as well as the “Industry 4.0” chapter, is based on empirical research. Existing literature was examined and analyzed in order to provide the needed information and to answer the crucial questions.

The intention of the chapter with the title “Expert Opinion” is to confirm or to object the data and information collected in the literature review chapters. In order to do so, two interviews were conducted with renowned experts of the field. The questionnaire includes questions concerning Industry 4.0 in general as well as more detailed questions referring to the interconnection between the concept of Industry 4.0 and the environment.

The last chapter of this master thesis shows the results of the work conducted, a foresight concerning Industry 4.0 in general as well as with respect to its nexus with the environment, an overall conclusion and a precise answer to the research question.

2. Industry 4.0

2.1 Antecedents

Industry 4.0 is a synonym for the fourth industrial revolution. As the name already indicates, it ensues three major previous industrial developments. The first industrial revolution emerged at around 1750 and is characterized by the introduction of water and steam powered mechanical manufacturing facilities which led to the mechanization of production. One of the most important technological achievements that it brought about was the first mechanical loom in 1784. (Aichholzer et al., 2015)

Besides technological developments, the first industrial revolution also led to societal changes. Examples for this are strong reductions in famine as well as exploding population numbers in industrial countries. This was the case because people, on the one hand, benefited from improving transport systems providing basic supplies such as food and clothing and, on the other hand, people benefited from productivity gains in manufacturing and agriculture which in turn led to an increase in the quality of life. Frankly, the first industrial revolution also had its down sides for society. The importance of handcraft and agriculture in the classical way shrunk significantly, leading to the division of society into two classes: factory owners and factory workers. Only very few profited from suppressing and exploiting the general public and since classical jobs began to vanish, people had no other choice but to move into cities where they hoped to find employments in factories. (Bauernhansl, 2014)

Eventually, these developments led to the transition into the second revolution, which has not only been an industrial but also a civil revolution. At around 1870, the second industrial revolution evolved with the spread of electrification. In further consequence, this spread of electrification triggered mass production based on the concept of Taylorism (this term is derived from Frederic W. Taylor, who in essence brought about the assembly line production). An example for one of the first achievements regarding the newly developed industrial phase was the introduction of the apparently first production line in a slaughterhouse in Cincinnati in the year 1870. (Aichholzer et al., 2015)

Besides the already mentioned changes, the second industrial revolution is also the origin of other major developments, such as the invention and sophistication of electrical drives, combustion motors, etc.. Especially electrical propulsion systems enabled a switch away from central and towards decentral powered engines and machines. Contemporarily, the importance of petroleum rose, amongst other reasons, due to its perpetual applications in the chemical industry and as a consequence of this due to the application as a fuel for mobile systems (especially for automobiles). With respect to societal changes, all these developments led to an overall increase in the quality of life in industrial countries. Consequently, also the population numbers continued to rise. However, society began to develop a demand for prosperity and realized that the suppression and exploitation of factories workers has to come to an end. Due to the strong quantitative increase and the simultaneous reduction in prices for the various products coming from the new industrial mass productions, a major social revolution could have barely been prevented. This was the time when social democracy was founded and ideas of communism began to spread. Further, this time can be defined as the origin of today’s consumption-oriented prosperous society. (Bauernhansl, 2014)

The subsequent third industrial revolution can be depict as the phase starting in the 1960s, in the course of which the automated mass production through electronics and IT led to the succession of previous developments. A prime example for this industrial revolution is the first programmable logic controller, called Modicon 084, which went into operation in 1969. (Aichholzer et al., 2015)

As the third industrial revolution went on, markets started to become saturated since most basic needs of the prosperous society were satisfied. This led to a step by step change from seller’s to buyer’s markets, meaning that it was not about producing as much as possible anymore. Customers became more nuanced and virtues such as quality and individuality gained importance. Hence, a constant and globalized availability and accessibility of knowledge appeared, which was driven by information and communication technologies and later on by the internet. This was the time when modern industrial society began to life beyond its means and in a sense this phase is not over yet. (Bauernhansl, 2014)

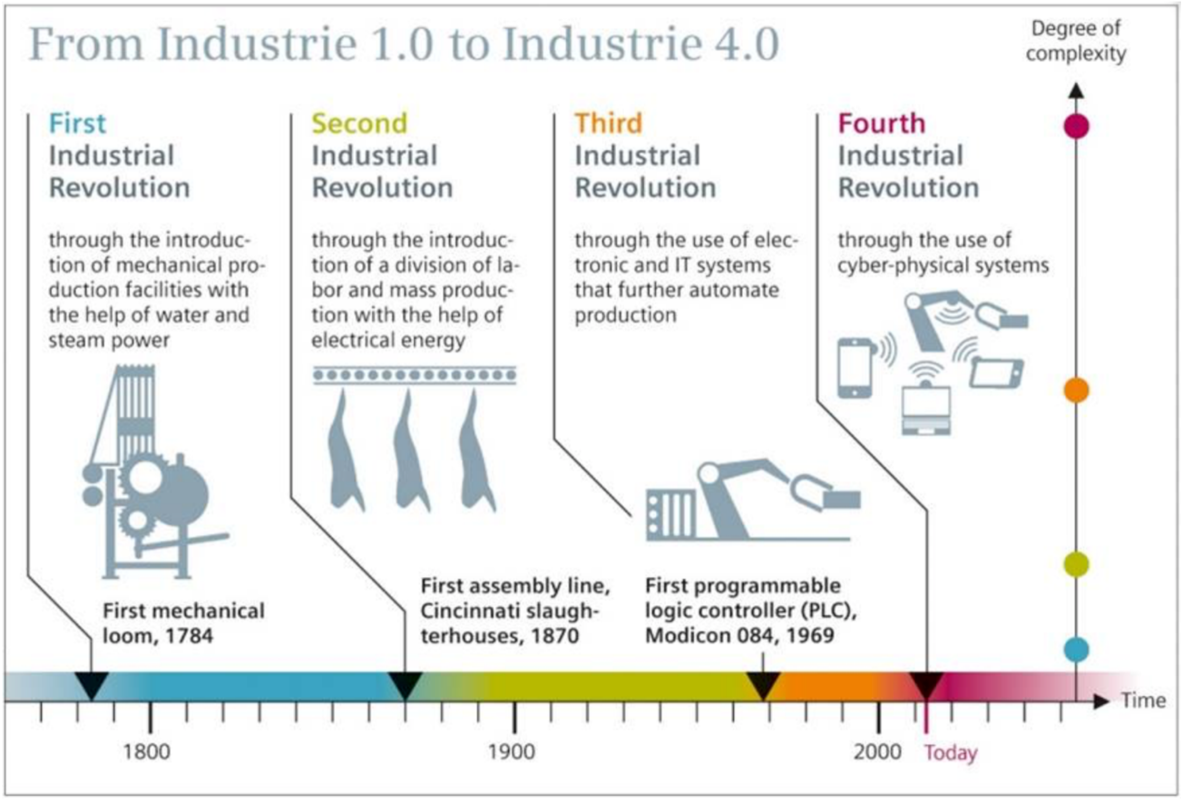

Figure 1: The Industrial Revolutions (MacDonald, 2016)

Figure 1 visualizes the four industrial revolutions in a graph by showing the interrelation between the factor time and the degree of complexity with time being on the x-axis and the degree of complexity on the y-axis. The graph depicts that the degree of complexity augmented with time, meaning that with every major transition the industrial standard was raised and technology became more sophisticated. Today, the transition from the third to the fourth industrial revolution is taking place, with some early adopters already being one step ahead and others slowly but steadily preparing for this transition.

2.2 Why Industry 4.0?

The intention of this chapter is to give an answer to the question why the next step in the industrial evolution is due, what the reasons for this progress are and why Industry 4.0 seems to be the solution.

According to a study conducted by McKinsey (2012), the share of the global population that actively participates in consumption is expected to increase significantly over the next few years and decades. Back in 1990, only 1.2 billion people were able to spend more than 10 US $ per day. 20 years later, this share almost doubled and the trend continues. By 2025, an estimated 4.2 billion people will be able to spend more than 10 US $ per day. These numbers show that a substantial increase of people participating in the global consumption lies ahead and thus, growth of the demand side can be regarded as guaranteed.
Further, this growth in demand will be most significant in developing markets, for which forecasts predict an aggregated trebling of purchasing power from twelve to 30 billion US $. Concurrently, demographic developments will play an increasingly relevant role. Urbanization is going to proceed in such a way that by 2050 approximately 60 to 70 per cent of people will live in cities and people's mean age will have risen by a scope of ten years by then. Hence, demand is assured but the manner of consumption will change considerably. In developed countries, the focus will be on highly individualized products, which means that productions have to be tailored on the specific requirements of the individual customer. That implies a shift towards personalization, while in developing countries the emphasis will increasingly be put on regional products that are oriented towards the needs of the markets with respect to functionality, design and costs. (Bauernhansl, 2014)

While all this shows that there will not be any problems on the demand side, the odds are that there might be a growth problem on the supply side. With the current value creation system, meaning the accepted and implemented processes that create additional value, it will not be able reach the required growth. This is because of the depletion of relevant resources. It takes nature one million years to create the amount of fossil energy sources that humanity currently exhausts per year. Obviously, sooner or later there needs to be a shift away from fossil fuels simply due to the fact that mankind is running out of them. An additional obstacle is the fact that predictions forecast a doubling of energy demand under the business as usual scenario (continuation of all processes as they are now) by the year

2050. All this poses major risks to the earth's nature, biodiversity and climate. (Zhang, Cai and Hu, 2013)
In order to overcome the previously mentioned challenges, a change of paradigm in how to deal with factors of production has to happen. The method of how to create additional value needs to be entirely modified. This concerns factors such as energy, resources, labor, knowledge, capital and many more. (Bauernhansl, 2014)

In the course of a fourth industrial revolution, a reversal of all factors of production will be required if the goal of a sustainable future unison between supply and demand shall be attained. One of the most important areas of adaptation is the energy sector. Therefore, an energy revolution is needed in order to alter the current course. This means that a shift away from fossil fuels and towards renewable energy and an even better energy efficiency has to take place. Presumably, even more important than an energy turnaround will be a change in resources. Hence, the crucial questions are whether it is possible to reach a circular economy and how to use resources in a sustainable way? The reduction and eventually the termination of the exorbitant generation of waste and emissions is a very important first step. (Braungart and Donough, 2008)
Another major topic is the imminent change in labor and working conditions. Taking into consideration that all resources involved in the various manufacturing processes need to be used in a more efficient way in order to stop profusion, it is no surprise that this is undoubtedly also going to affect the resource labor. A working environmental has to be created that allows employees to fully evolve their skills in order to keep them motivated, productive and pleased. (Bauernhansl, 2014)

The alteration of all the previously explicitly as well as the briefly mentioned factors of production will eventually be enabled by information and communication technology. It is be expected that in this field, a lot of essential innovations will occur in order to allow a transition from the current state-of-the-art to the foreseen fourth industrial revolution. The requirement of creating value in a more sustainable way and concurrently satisfying the requirements of personalization, regionalization as well as globalization obviously leads to a significant increase in the complexity of all processes involved. In order to cope with this difficult and apparently inexpugnable task, I 4.0 is defined to be the suitable underlying concept to usher industry and all that it entails into future. (Bauernhansl, 2014)

2.3 Derivation of the Term Industry 4.0

The term Industry 4.0 made its first appearance in a German scientific publication by Kagermann et al. (2011) in which the authors elaborated the main ideas of the concept. This exact publication then was the foundation for the manifesto called “Industrie 4.0” that the German National Academy of Science and Engineering published in 2013. The intention of this eponymous future-oriented project was to formulate a German high-tech strategy for the near future. The institute that is responsible for addressing and developing Industry 4.0-related topics at the European level is the Public-Private Partnership for Factories of the Future. (Stock and Seliger, 2016)

Already within the first years of the project, not only in Germany but also in Europe and even on a worldwide scale, the concept of Industry 4.0 and its suggested pathway towards the fourth industrial revolution reached a broader social and political base. (Aichholzer et al., 2015)

Ab initio, amongst the promoters of the outset were government officials, associations, academics and leading companies. It is rather unlikely that, at the time when the project with the intention to deepen the knowledge and to promote the importance of the digitalization of manufacturing processes was launched, any of the involved persons expected that their newly introduced concept would develop to such a widely examined, discussed and applied aspect. (i-Scoop, 2017)

The meteoric rise in popularity and consequently in usage of the term Industry 4.0 diluted the actual meaning of the notion behind the term. In order to get a profound idea about the core elements and characteristics of the concept of I 4.0 and to dissociate the important from the less important aspects, it is necessary to impartially examine and analyze existing literature concerning suitable and adequate scientific definitions. (Bauernhansl, 2014)

The findings of this can be found in the following chapter.

2.4 Definition of Industry 4.0

Due to the high complexity and the rather short time of existence of the concept and term Industry 4.0, there is not one explicit and commonly accepted definition. However, academics and experts in the field provide various definitions that slightly differ but inherently all include the same aspects, as the following selection of definition shows.

According to Aichholzer et al. (2015), Industry 4.0 is defined by intelligent, digital, networked and self-managed production processes which can be achieved via the confluence of the internet, information technologies (IT) and production techniques. The essential potential of the concept of I 4.0 is to establish a new quality of production technology as well as the combination of information and communication technology.

According to Rüßmann et al. (2015), Industry 4.0 is defined as the digital transformation of production, which takes advantages of technologies and concepts such as Big Data, artificial intelligence (AI), robotics, Internet of Things (IoT) and so on leading to “connected factories, smart decentralized manufacturing, self-optimizing systems and the digital supply chain in the information-driven cyber-physical environment”.

According to Roth (2015), Industry 4.0 does not require a definition of the term that the academic world agreed on but as soon as a given set of characteristics are given, one can call it Industry 4.0. This is because a whole concept cannot be narrowed down to a definition. He argues that the fourth industrial revolution is mainly induced by IT and requires companies in the manufacturing sector to effectuate four specific characteristics by the year 2025. These characteristics that define Industry 4.0 are a high degree of individualization of manufacturing in addition to the already existing standard settings, highly flexible and at the same time efficient production processes down to one uniquely customized product, extensive implementation and inclusion of customers and business partners into business and value creation processes, as well as the connection of manufacturing and high-end services which lead to so called hybrid products (an example for a hybrid product would be to sell mobility rather than a vehicle).

According to a study conducted by UNIDO (2017), Industry 4.0 is expected to have a major impact on economies, industries as well as lifestyle patterns all around the world. This process involves the nexus of the physical world of industrial production with the digital world of IT, which is also known as cyber-physical systems (CPS). Industrial manufacturing processes become digitalized and interconnected by self-organization and self-steering of factories.

In order to round this up, the last approach to define Industry 4.0 is a rather generic and broad one: Industry 4.0 represents the fourth industrial revolution in manufacturing and industry. It is the industrial transformation with data exchange, automatization, cloud, Big Data, robots, CPS, AI, IoT as well as autonomous industrial techniques in order to accomplish smart industries and manufacturing goals in the intersection of innovation, people and new technologies. The principal goals of the concept are automatization, improvements of processes and optimization of productivity. The subordinate goals are innovation as well as conversion to new business models and thus, to new sources of revenues based on services and information. Other names for I 4.0 are for instance “smart industry”, “intelligent industry”, “smart factory” or “smart manufacturing”. (i-Scoop, 2017)

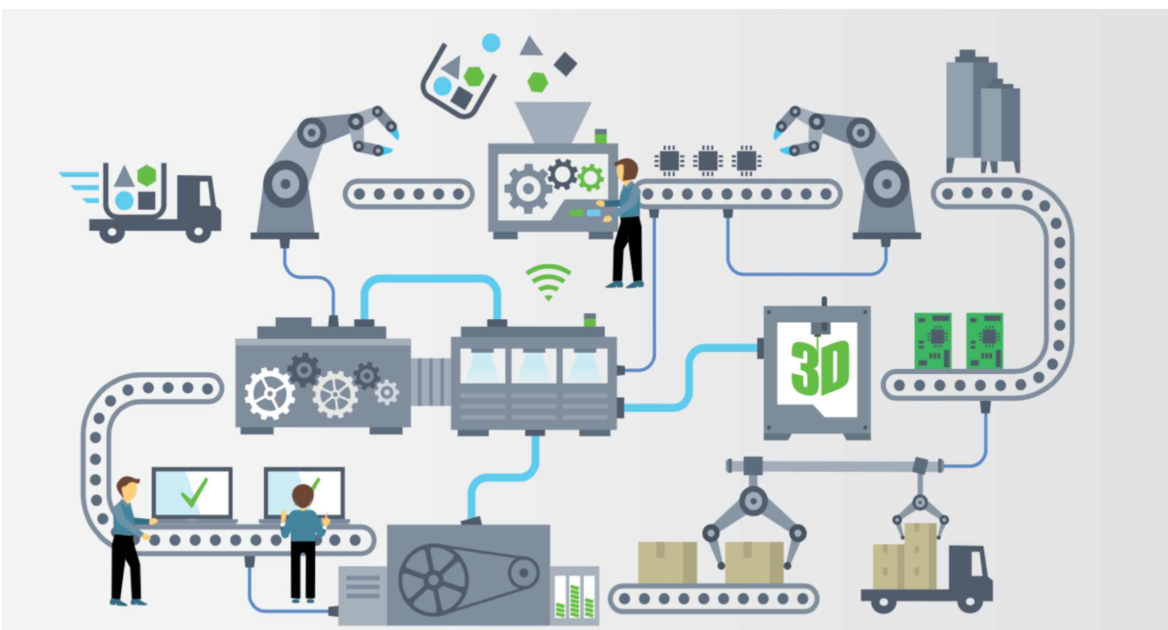

Figure 2: Industry 4.0: Digital and Interconnected Production (UNIDO, 2017)

Figure 2 illustrates how a digital and interconnected production under the concept of Industry 4.0 could look like. The different symbols represent technological developments and aspects such as interconnectivity, IoT, automatization, Big Data, etc..

2.5 The Nine Technological Pillars of Industry 4.0

The Boston Consulting Group came up with nine sophisticated technologies that form the foundation of Industry 4.0. The findings from BCG not only got approved by numerous distinguished research institutes and experts but furthermore, quite some academic literature used this science base as a foundation to base their research on. It is argued that the advancement of these technologies will make it possible to collect and analyze enormous amounts of data in order to enable faster, more flexible and more efficient manufacturing processes leading to goods of higher quality and lower costs. Further, these underlying technologies will generally have the effect of increasing productivity, shifting economics, enhancing growth and modifying the workforce profile. These technologies provide technical as well as economic benefits for their adopters and eventually, they will change the competitiveness of regions and corporations. Some of the building block technologies of I 4.0 are already implemented in manufacturing, while production is lagging behind. The implementation of I 4.0 technologies will transform production in such a way that isolated and optimized cells will be combined to a fully integrated, automated and optimized production flow which will lead to higher efficiencies and will radically change traditional relationships between supplier, producers, customers as well as among human and machine. (Rüßmann et al., 2015)

On the next page, Figure 3 shows the nine technologies that according to Rüßmann et al. (2015) are leading to a transformation of industrial production. Therefore, these partly already existing but mostly new technologies are the pivotal building blocks of the concept of Industry 4.0. If a company decides to implement these technological novelties or in case an industry defines some of them as their standard, this unambiguously equals an implementation of Industry 4.0.

Subsequent to Figure 3, all of the nine depicted technologies are described and characterized with regards to their respective benefits, expectations, state of application, etc..

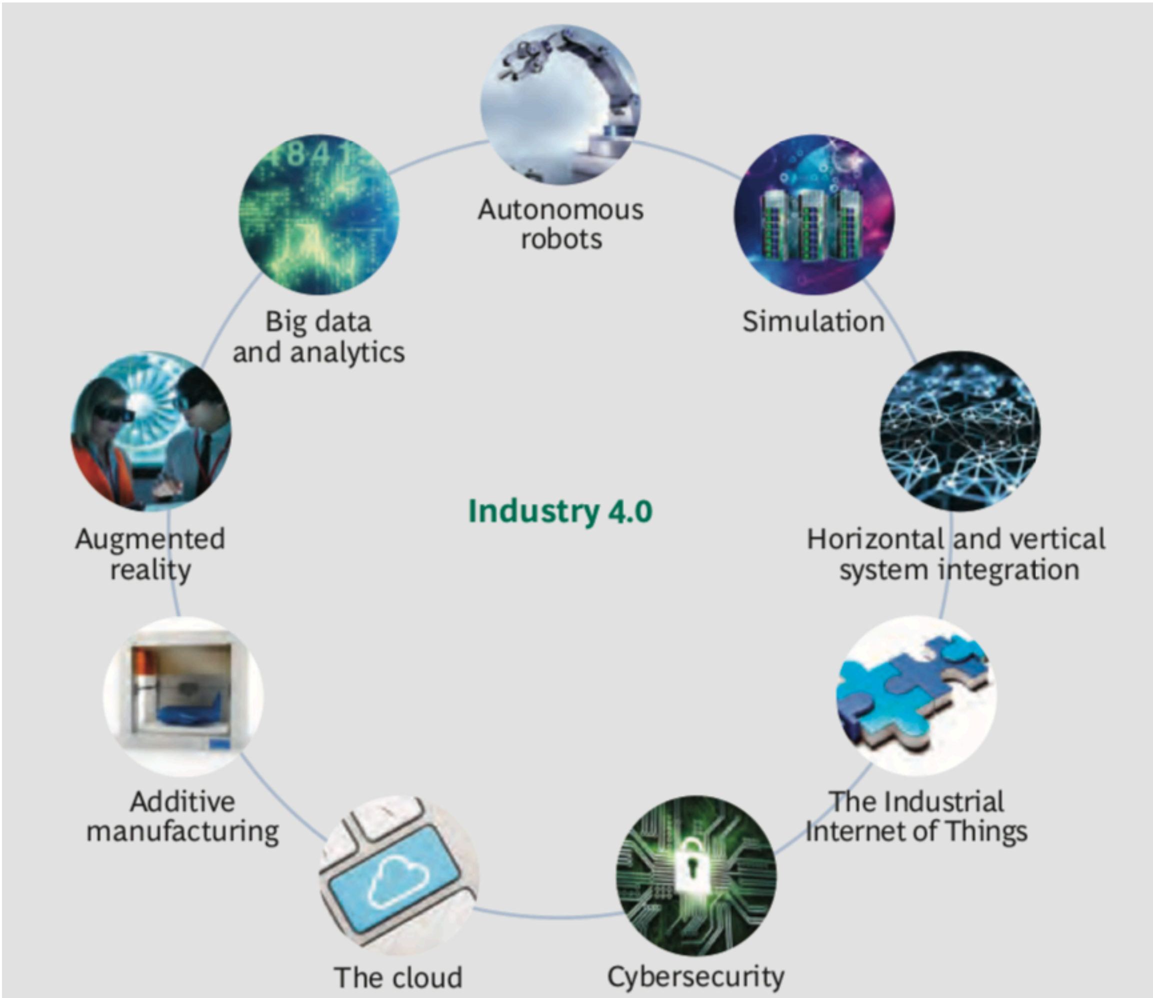

Figure 3: Nine Technologies are Transforming Industrial Production (Rüßmann et al., 2015)

2.5.1 Big Data and Analytics

Analytical operations based on large data sets recently increasingly gained importance in the manufacturing world. Some of the arguments in favor of it are that it helps to optimize production quality, to save energy and to improve equipment services. Referring to Industry 4.0, the comprehensive collection and evaluation of data coming from various sources, such as production or customer-management-systems, is going to become the standard in order to enable real-time decision making. (Rüßmann et al., 2015)

2.5.2 Autonomous Robots

Robots are employed since a long time by manufacturers in different industries in order to cope with complex tasks. However, the fields of application for robots are only just evolving and they gain even greater utility by improving decisive properties such as autonomy, flexibility and cooperation. The eventual aims are that they interact with one another as well as that they work side by side with humans and, thereby, not substitute jobs but make them more save, productive and consequently more easy. The robots of the future will be of lower costs and will have a larger range of capacities compared to the ones used in manufacturing today. (Rüßmann et al., 2015)

2.5.3 Simulation

3-D simulations of, for instance, products, materials or even production processes are in use already today. While at the moment they are mostly used in the engineering phase, the scope of application is expected to expand. Simulations will be used for all kinds of plant operations in the future. These highly sophisticated simulations will use real-time data in order to reflect the actual world and all the relevant aspects that it comprises (such as products, machines or humans) in a virtual model. The result of this is that it allows manufacturers to test and advance the various settings of machines for the upcoming products in a virtual model before actually changing the physical process. Two advantages are the facts that it minimizes deadlocks of machines and contemporaneously increases quality. (Rüßmann et al., 2015)

2.5.4 Horizontal and Vertical System Integration

Nowadays it is not common but rather an exceptional case when IT systems are fully integrated, meaning that neither suppliers, companies and customers nor different departments such as engineering, production and service usually have a close nexus. With the implementation of the concept of I 4.0, cross-company and even universal data-integration networks will evolve and in the course of this facilitate completely automated value chains which allows companies to have more detailed information on and better connections between its departments, functions and capabilities. (Rüßmann et al., 2015)

2.5.5 The Industrial Internet of Things

For the time being, only few sensors and machines in the manufacturing sector are networked and deploy embedded computing. Typically, their organization structure has the form of a vertical automation pyramid, which means that generally sensors and field devices are characterized by limited intelligence and automation controllers. The data derived from it gets fed into an overarching manufacturing-process control system. The additional value that the industrial IoT offers is that it connects more devices and enriches them with embedded computing. An implication of this is that field devices can communicate and interact with one another as well as, if necessary, with further centralized controllers. Further, it decentralizes analytics and decision making, which in turn enables real-time responses. (Rüßmann et al., 2015)

2.5.6 Cybersecurity

The status quo in a lot of companies is that they rely on still unconnected or closed management and production systems. The increased connectivity as well as the constant use of standard communication protocols that Industry 4.0 entails, leads to a significant augmentation in the requirement to adequately protect critical industrial systems and manufacturing lines from cybersecurity threats. Consequently, it is of outmost importance to secure reliable communications as well as the elaborated identity and access management of machines and users. In order to cope with these challenges, several industrial enterprises began to join forces with cybersecurity firms via partnerships or acquisitions. (Rüßmann et al., 2015)

2.5.7 The Cloud

Already today, the majority of companies are using cloud-based software for certain enterprise and analytics applications. However, with the advance of I 4.0, further production-related endeavors will require stronger sharing of data across sites and company boundaries. This should not state a problem, since at the same time, the capability of cloud technology is expected to constantly increase and to achieve reaction times of only a few milliseconds. The result will be that machine data and functionality will increase to be cloud-based, which renders more data-driven services for production systems possible and even systems that monitor and control processes will be deployed to the cloud. (Rüßmann et al., 2015)

2.5.8 Additive Manufacturing

Just like 3-D printing, additive manufacturing is something that most companies only began to adopt. In most cases, it is used to prototype and produce individual components. With the rise of I 4.0, the various possible additive-manufacturing methods will be vastly used in order to produce small quantities of customized products that offer beneficial effects concerning construction such as complex and lightweight designs. Reduced transport distances as well as stock on hand are advantages of highly performing and decentralized additive manufacturing systems, just to name two. (Rüßmann et al., 2015)

2.5.9 Augmented Reality

The selection of parts in a warehouse or the transmission of repair instructions via mobile devices are examples of services that are supported by augmented-reality-based systems. The herewith associated systems are still in the early stages of development. However, forecasts for the future predict that companies will increasingly rely on the use of augmented reality in order to provide workforce with real-time data which shall lead to an improvement concerning decision making and work procedure. (Rüßmann et al., 2015)

2.6 Characteristics of Industry 4.0

Essentially, the concept of Industry 4.0 refers to new standards in production technology and to a new quality in combining information and communication technology. It represents a highly self-configuring, autonomous and sensor-based production system in which communication between people, machines, robots, logistic systems, facilities, materials and equipment takes place via embedded hard- and software, new interfaces and internet-based wireless technologies. The smart factory is the place where all of this takes place and consist of close connections and highly complex value networks with relevant suppliers, service providers, producers and customers. Both, the horizontal integration in the value network as well as the permanent vertical integration of several process hierarchies and steps within the intelligent factories is organized by cyber-physical systems. The result of this will be more digitalized factories with possibly fewer people due to a higher degree of automation. This paradigm shift in the interaction between machines and human beings leads to a new intensity and quality of socio-technical interactions. Given the value networks under I 4.0, decision making becomes a process involving humans and machines. In such production settings, the intensity of cooperation increases significantly and the IoT is a prerequisite concerning infrastructure. Besides the rise of smart factories, there will also be an emergence of smart products. One of their main features is the fact that they know about their own manufacturing process as well as future use and that they have recourse to this information in order to proactively support their own production. The technological foundation for developing such CPS has shown major progress over the last years. Now, designing and modelling appropriate CPS is going to be a decisive factor with respect to the degree of embodiment of I 4.0 networking solutions in practice. (Aichholzer et al., 2015)

Decidedly, I 4.0 has the potential to truly revolutionize industrial manufacturing processes. Yet, it is of outmost importance to consider the various advantages as well as the potential drawbacks that companies might face in the course of implementing the technologies coming with I 4.0. In the following two chapters, a number of benefits and challenges will be stated and analyzed in detail.

2.6.1 Goals and Benefits of Industry 4.0

The main aim of Industry 4.0 is to not only make the manufacturing industry but also all related industries faster as well as more efficient and customer oriented, while simultaneously finding new auspicious business models and opportunities in the course of developing and implementing automatization and optimization. (i-Scoop, 2017)
Hence, optimizing processes can be stated as one of the most prominent benefits of Industry 4.0. If one imagines a smart factory that contains thousands of smart devices with the ability to self-optimize production, this leads to a production with a down time of almost zero. For industries that use highly sophisticated and expensive manufacturing equipment, such as the semi-conductors industry, this is extremely important. All companies that are able to constantly and consistently use production will strongly benefit from this ability. According to a study conducted by PwC, the European industry will ideally generate additional revenues of approximately 110 billion € with digitized products and services on an annual basis. (Schrauf and Berttram, 2016)

Further benefits of I 4.0 are the potentials for cost reduction and effective use of resources. In the light of this, three areas can be identified which are expected to experience an increase in resource efficiency or a reduction of costs. The first one refers to financial resources, meaning investment and operating costs. The companies optimizing their value chains and increasing flexible manufacturing automatization will consequently reduce their fixed capital. Secondly, one area with a lot of potential refers to costs coming from raw and operating materials as well as from energy. A reduction in consumption implies a reduction of costs. In order to achieve this, processes have to be designed more efficient, maintenance has to be conducted anticipatory, less waste has to be produced, the amount of errors has to minimized and quality control as well as production planning has to become more efficient. Additionally, supply risks has to be reduced while the environmental sustainability needs to be increased. The third area is the one of human resources. The higher the degree of automatization in a company, the lower the requirement of personnel related to the respective production volume. Consequently, under Industry 4.0 conditions, the costs for personnel in relation to the respective production value will be reduced, which might even reduce costs in absolute terms. (Aichholzer et al., 2015)

Industry 4.0 goes beyond cutting costs and enhancing resource efficiency. The integral vertical and horizontal integration and networking will result in various advantages. For instance, positive effects on flexibility as well as flow time, which in turn lead to a significant increase in productivity and revenues. This is one out of many reasons why experts see I 4.0 as the key to secure a competitive industrial base in the global race for economic power. (Aichholzer et al., 2015)
According to the consulting company Roland Berger, expectations for the world economy are an annual growth of around 2.5 per cent between 2014 and 2020, while forecasts for the Industry 4.0 segment, including users and suppliers, predict an expected annual growth of 6 per cent. In monetary means, that equals approximately 800 billion US $. (Blanchet et al., 2014)
In this context, a study conducted by PwC argues that industrial companies in Germany expect efficiency and productivity gains of 18 per cent and more within the upcoming five years. This is based on better digital control of vertical and horizontal value chains. Furthermore, it is expected that the networking and digitalization of own products and services will result in an annual 2-3 per cent increase in revenues. This percentage corresponds to additional revenues worth 30 billion €. (Schrauf and Berttram, 2016)
In the case of Austria, I 4.0 solutions potentially lead to an increase in revenues for the national manufacturing sector by approximately 2.8 billion € per anno. (Busch et al., 2015)

Another characteristic that is expected to turn out to be a benefit of I 4.0 is customization, meaning custom-made mass production with maximally small batch sizes and a higher variability. One advantage of this approach is that ideally only the products that eventually will be sold are actually produced. (Aichholzer et al., 2015)
Another advantage coming from the creation of a more flexible and customer-oriented market is that it helps meeting the needs of the population in a fast and smooth manner. Further, it is considered to close the gap between manufacturer and customer, since it allows direct communication amongst them. (Cleverism, 2017)

Also the opportunity for implementing new business models and services is a benefit, since it implicates value-added as well as market potentials. Digital business models that target the integrated use and analysis of data coming from the entire value network and that provide tailor-made solutions can lead to substantial additional benefits for businesses as well as for end users. Potential areas of application are project management, logistics as well as already mentioned areas such as maintenance, customization and augmented reality. In general, the collection, analysis and use of Big Data opens up new possibilities. For instance, in the field of development of downstream innovative B2B services for Industry 4.0. (OECD, 2015)

One last benefit that shall be mentioned is the expected push in research. Besides offering new business opportunities, adopting I 4.0 technologies is expected to result in a push for research in fields like IT or cyber security. The new technologies of the new industrial phase will require a new set of skills and therefore, education and training will be affected in particular in order to provide such an industry with the skilled labor that it requires. (Cleverism, 2017)
In the case of Germany, a prompt adaption to this requirement is of outmost importance, since the growth provided by the implementation of I 4.0 and all its entailed technologies is expected to lead to an increase in employment in the manufacturing sector in the range of between six to ten per cent over the next ten years. (Rüßmann et al., 2015)

2.6.2 Challenges and Downsides of Industry 4.0

A concept with an enormity like that of Industry 4.0 clearly does not only entail advantages and benefits but also challenges and potential disadvantages. At the present time, I 4.0 is rather a vision than reality. Therefore, in the course of a transformation with such an extent, numerous changes might occur that can have negative impacts on the company and industry level but also on the societal level. Since the implementation steps of I 4.0 are still in their early stages, the various expected risks are subject to a relatively high degree of uncertainty. However, there exist somewhat precisely defined ideas on how the implementation of I 4.0 has to take place in order to have the smallest number of disadvantages and the largest number of benefits. (Helbing, 2015)

One of the areas in which significant changes are to be expected is employment. The increasing importance and implementation of integrated production systems will entail lasting changes regarding organizational and work structure, which will lead to a number of major consequences on several levels. (Smith and Anderson, 2014)
It cannot yet be defined whether I 4.0 will have a predominantly positive or negative impact on the volume of employment, since this depends on a lot of development. For instance, the degree to which human labor will be substituted by automatization, the extent to which jobs

in other sectors will grow as well as wage cost developments. In the case of Germany, forecasts predict either an increase or a decrease of approximately 1.5 million jobs in manufacturing. Automation and labor costs are the decisive factors in this respect. (Spath et al., 2013)

One thing that is certain is that with the worldwide adoption of I 4.0, workers will have to acquire new sets of skills. On a short-term basis, the trend of increasing automatization might displace some low-skilled workers performing repetitive and simple tasks. However, the rise in importance and usage of software, connectivity and analytics will result in an increasing demand for employees that have competencies in IT technologies and software development. Respective education and training initiatives may help prevent above-averagely increasing unemployment rates. Especially the workers that conduct rather easy and repetitive tasks will face challenges in keeping up with the industry. Overall, the transformation in competences on the labor market is going to be one of the key challenges in the light of I 4.0. (Rüßmann et al., 2015)

Another challenging aspect that the implementation of Industry 4.0 technologies brings with it is the IT security risk. Online integration and cloud data storage enables data leaks, cyber theft as well as security breaches in general. It is expected that a lot of capital has to flow into upgrading IT security in order to guarantee operational and product safety and to prevent the loss of relevant data, which eventually might hurt the respective company's reputation. (Cleverism, 2017)

A lot of the systems that are in place, were developed for offline applications and connecting them with the internet makes those systems vulnerable to attacks and disturbances. In general, it can be said that the complete and automated networking between companies comprises substantial potential when it comes to enhancing efficiency and optimizing resources. However, exactly this also includes a lot of potential security risks since a system that is not adequately protected, can be disrupted and in such cases, enormous amounts of crucial corporate information as well as personal data of employees and customers are affected. Protection can only be successful when each networked end is able to assess the others trustworthiness and to identify it as safe. (Aichholzer et al., 2015)

A further inevitable challenge is that a transformation of such an extent will require enormous investments into new technology. Raising the capital needed might pose a problem in particular to small and medium sized enterprises. In Germany alone, the adaption of manufacturing processes to I 4.0 standards will require an investment of about 250 billion € over the next ten years. This corresponds to 1 to 1.5 per cent of the total manufacturing sector's revenues. (Rüßmann et al., 2015)

One last emerging challenge which shall be mentioned refers to regulations, since the trend towards I 4.0 has quite some implications for legal framework. The development and implementation of new technologies not only entails uncertainty about the legality of the respective technology and its applications but also might challenge the necessity of existing regulations. The key areas of adjustments will be data protection, liability as well as labor laws. Appropriate regulatory frameworks have to fulfill the requirement to establish legal certainty, to strengthen responsibility, acceptance and competition as well as to ensure the feasibility of regulations. Innovations and constant developments will pose a challenge for legislation, offer a chronic lack of enforcement and therefore, require permanent adjustments. All in all, the challenges arising from the regulatory framework, together with other aspects such as employment or IT security, are expected to be of outmost importance and their respective solutions represent a crucial success factor. (Aichholzer et al., 2015)

3. Industry 4.0 and the Environment

Nowadays, major industrial developments cannot only be driven by economic factors. In addition to economic, also political and social factors need to be taken into account. Examples for this argument are the pressing problems of the 21st century, such as environmental pollution, reduction of natural resources or climate change. (Erol, 2016)
Industry 4.0 constitutes such an industrial development and its advancing implementation inevitably entails fundamental changes from an economic as well as a social perspective. The technologies underlying the concept of I 4.0 have the potential to not only boost productivity, but also to create environmental and social value. In order to successfully usher this new industrial revolution, it is of importance to identify the respective technological developments that have the largest potential to increase environmental and social value, while, at the same time, being economically beneficiary. This can only be in the interest of businesses as well as policy makers, since the improvement of quality and long term sustainability of economic growth is a common goal. (Green Alliance, 2018)
Even though the concept of I 4.0 does not explicitly name ecological sustainability as a major objective, the production technology and operations research community have repeatedly mentioned the overall positive ecological impact and the improving sustainability that the it entails. (Erol, 2016)
Therefore, more efficient use and conservation of resources can be stated as inherent goals of Industry 4.0 with a direct effect on the environment. Due to the continuous and integral collection of data, it becomes possible to reach comprehensive transparency e.g. regarding the resource consumption during the manufacturing process of a product and the respective potential savings. (Schlick et al., 2014)

3.1 Environment

Defining the term environment is a crucial task in the light of the research question of this master thesis, namely what the most prominent positive as well as negative effects on the environment coming with the implementation of Industry 4.0 technologies are. According to Principle 2 of the Declaration of the United Nations Conference on the Human Environment, which took place in Stockholm in 1972, the term environment is defined as “the natural resources of the earth, including the air, water, land, flora and fauna and especially representative samples of natural ecosystems”. This is a definition in the broadest sense. In 1976, the European Commission submitted a journal that defines the coverage of the term environment in a somewhat more narrow way as follows: “The term ‘environment’ is used to cover all those elements which in their complex inter-relationships form the framework, setting and living conditions for mankind, by their very existence or by virtue of their impact.”

Concerning the effects that humans can have on the environment, there are hardly any boundaries or limitations and their connotation is mostly a negative one. Humans had an impact on vegetation ever since (for instance due to the use of fire) as well as on animals (especially due to domestication and habitat changes), on soil (change in nutrient content leads to changes in agriculture), on the waters (such as modifications of water bodies and their pollution on and under the ground), on the climate and the atmosphere (most prominent examples are the anthropogenic greenhouse gases). (Goudie, 2006)
On the other hand, examples of explicitly positive effects of humans on the environment could for instance simply be recycling, preserving wildlife, creating more green and open spaces in urbanized areas as well as implementing environmental protection laws. (Brenner, 2018)

3.2 Sustainability

Sustainability is a crucial issue of increasing importance for the present and future generations. In its original sense, sustainability was mainly oriented on the environment. However, this focus changed over the years. In current literature, the term is defined as consisting of three rather than of one dimension, namely environmental, social and economic. Sometimes even adding technology as a fourth dimension. (Baud, 2008)
Looking at the way consumption takes place at the moment, one could assume that the stock of natural resources will last forever or that the regenerative capacity of the environment is able to compensate all human exploitations. However, this is not the case. This is why from an economic, social, political as well as obviously from an environmental point of view, all sustainability issues will gain in influence. Especially manufacturing is going to be strongly affected by sustainability issues, since it is one of the main pillars of modern civilized lifestyle. Hence, manufacturing has the potential to play an important role in paving the way towards a more sustainable future. In order to actually realize a paradigm change towards a more sustainable future, all upcoming technological developments shall be required to not only meet I 4.0 standards but also to meet environmental standards. Particularly for the manufacturing sector, new technologies and consequently new business

and life style models have the capability to become the cornerstones of a new sustainable world. (Garetti and Taisch, 2012)

In our modern society, manufacturing is the source of all goods for living, transportation, entertainment, production, safety, etc.. Thus, on society's way to sustainability, the implementation of sustainability in manufacturing will without any doubt have one of the most important and positive contributions. In this regard, technological development is going to be a critical factor in environmental preservation. Respective appropriate technologies are able to promote a positive relation between social and economic human needs as well as environmental constraints. (Garetti and Taisch, 2012)
For instance, experts such as Pacala and Socolow (2004) state that the carbon and climate problem could, from a technical point of view, theoretically be solved within the upcoming half-century due to the fact that the necessary scientific, technical and industrial know-how already exists. Yet, the decisive factor is to which degree this is of relevance to businesses and policy makers since those are the ones with the power to make decisions that lead to changes. Consequently, technology as such has to be considered as a fundamental enabling component of sustainability.

Besides technology, also education is a fundamental enabling component of sustainability, especially with respect to manufacturing. Education is an indispensable prerequisite for people to adequately address the sustainability goals through appropriate lifestyles as well as through appropriate use of products and technology. This is a requirement that needs to be met in order to enable progress regarding sustainability. In turn, technology and education are the foundation for Sustainable Manufacturing (SM). This is a concept that goes hand in hand with the concept of Industry 4.0, but further implies standards and adaptions in order to make the upcoming revolution not only an industrial but also a sustainable one. SM is defined as the ability to use natural resources for manufacturing in a smart manner and thereby creating products and solutions that, especially due to new technologies, are capable of satisfying social, economic and environmental aims. Meaning that the environment will be preserved, while the standard of living will continue improving. (Garetti and Taisch, 2012)

3.3 Key Elements in Approaching Sustainable Manufacturing

One decisive element in achieving sustainability that can definitely be implemented in the concept of Industry 4.0 is the sustainable design approach for new products and services leading to a considerably better environmental and thus, to sustainable performance. Ideally, an innovative approach to sustainable design is characterized by a broad range of applications for improving industrial products, manufacturing processes, product-service systems as well as production machines and systems. Various methodologies for solving these complex challenges have already been and will continue to be proposed. One example in this regard is the in the industry already known “Design for X” (where the X e.g. stands for recyclability, energy saving, disassembly, etc.). Another example of a rather new concept is to conduct product assessments through the products entire life cycle, which just like “Design for X” is an example for a technological development that is expected to increasingly emerge under Industry 4.0. (Garetti and Taisch, 2012)

Another critical element in achieving sustainability contemplated from the manufacturing sector refers to labor as a resource. Without deflating the importance of technology and digitalization, humans will continue to be the ones organizing value creation also under the concept of Industry 4.0. Stock and Seliger (2016) offer three sustainable approaches for coping with the social challenge that I 4.0 entails. The first suggested approach is to increase training efficiency of workers by combining new information and communication technologies. Secondly, establishing new CPS-based approaches of work organization and design can foster creativity and increase intrinsic motivation. The third approach refers to the implementation of individual incentive systems in order to increase the extrinsic motivation.

Further, the manufacturing equipment also constitutes an opportunity towards sustainable manufacturing. In general, the manufacturing equipment that can be found in factories represents capital goods with a long life expectancy of 20 years and longer. In order to easily and cost-efficiently upgrade existing manufacturing equipment with sensors, actuator systems, the related control logics as well as further Industry 4.0 technology upgrades, retrofitting can be used as an approach for realizing CPS throughout factories with already existing manufacturing equipment. It is a low cost alternative to the new procurement of manufacturing equipment and, therefore, a particularly suitable option for small and medium sized companies. Retrofitting not only expands the life expectancy and facilitates the handling of upgraded manufacturing equipment, but further essentially contributes to the economic as well as the environmental dimension of sustainability. (Stock and Seliger, 2016)

Relating to the manufacturing equipment, it can be mentioned that I 4.0 technologies can minimize unreliable demand planning and overproduction. I 4.0 applications allow more accurate demand forecasts, which leads to a reduction in waste. This is because of the fact that overproduction as well as the inventory could be reduced by projecting the required input materials more accurate. Accurate demand forecasts will decrease the need for unnecessarily large amounts of raw material. Under such circumstances, less resources will be extracted for the production of new goods. (Blunck and Werthmann, 2017)

One major aspect that also has to mentioned in this respect is the combination of two trends, namely sustainable energy and Industry 4.0. So far, this approach has not attracted a lot of attention in research. However, there are various ways how sustainable energy concepts can be incorporated into digital factories. Fundamental prerequisites for this are data connection of the factories with the energy system in order to elaborate the current level of renewable energy in it as well as the market price. Thereby, energy consumption and generation can be converged. Demand response is one of the most prominent approaches in this field. The concept addresses the temporal flexibility of energy consumption and may be characterized as load curtailment, load increase and load shifting. It is of particular importance to time-flexible but energy intense production processes, such as chemical electrolysis. The general aim of the concept is to time production phases according to the availability of inexpensive electricity in the energy market. (UNIDO, 2017)

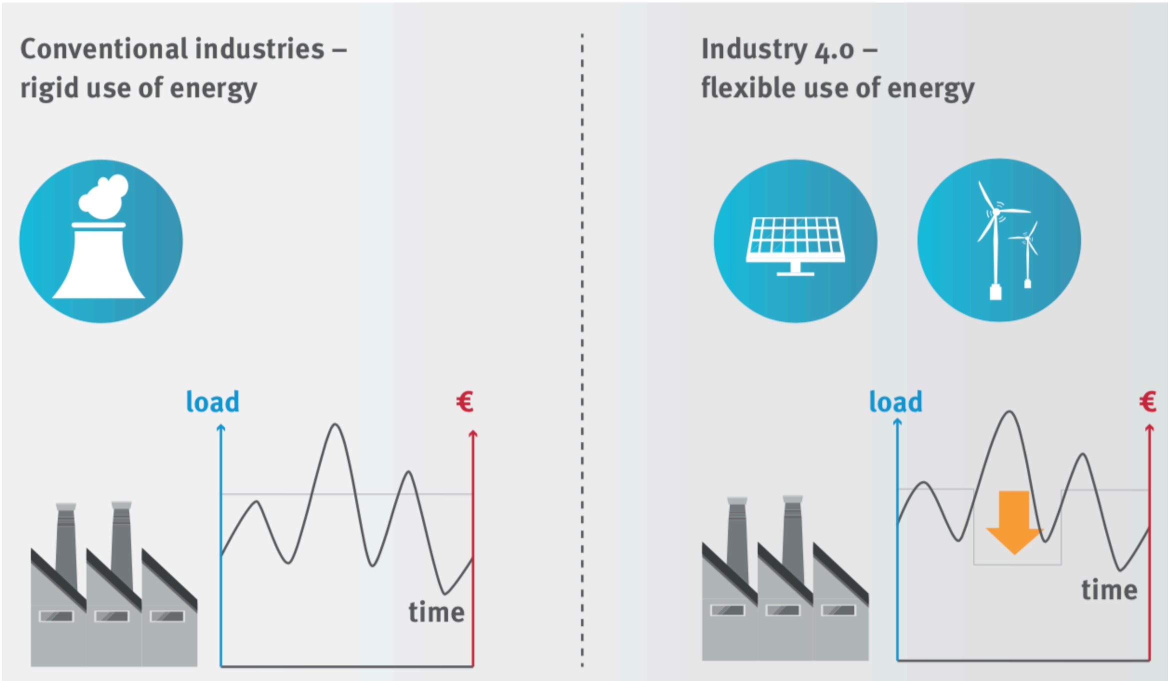

Figure 4: Producing in Smart Factories when Electricity is cheap (UNIDO, 2017)

Figure 4 shows how the total electricity load as well as the total electricity price decrease when timing certain, or ideally all, production phases according to the availability of inexpensive electricity coming from renewable energy sources. In conventional industries, one does not take into account preferable times for demanding electricity. Under Industry 4.0, one can use energy more flexible by having information on when electricity is cheapest and consequently adapting production phases according to these “ideal demand times”.

3.4 Industrial Pollution and Energy Consumption Development

The European economy is characterized by a strong industrial sector. This brings with it a number of far reaching advantages as well as disadvantages. The most prominent downside of Europe’s large industrial sector is the fact that it is one of the major sources of pollution. It is true that European industry’s environmental performance has improved over the past decades. Nevertheless, the industrial sector bears the responsibility for enormous amounts of pollution to soil, water, air and for the generation of vast amounts of waste. Some EU policies such as the Industrial Emissions Directive or the European Union’s Emissions Trading System delivered measurable achievements regarding the reduction of pollution. However, incentives to change operating practices, integrated approaches with stricter control of pollution at source and the use of innovative technologies will be necessary for a transition to a greener European industry. (European Environmental Agency, 2015) In this context, Industry 4.0 is promising concept, since it entails a number of advantages and desired characteristics.

Industry is a sector that emits significant amounts of air pollutants and greenhouse gases. In Europe, the industrial sector was responsible for 85 per cent of Sulphur dioxide (SO_2) emissions, 40 per cent of nitrogen oxide (NOx), 20 per cent of fine particulate matter ($PM_{2.5}$) and of non-methane volatile organic compounds (NMVOC) emissions, and 50 per cent of total greenhouse gas emissions in the year 2012. Figure 5 shows how the emissions of these pollutants coming from industry have reduced since 1990. Concurrently, the productive capacity of the European industrial sector has increased. The reasons for the reduction in industrial pollution were stronger environmental regulations, energy efficiency improvements as well as innovative pollutant abatement technologies. An addition driver for emission reductions was the emergence of a general tendency for the European industrial sector to gradually dismiss certain heavily polluting types of manufacturing. (European Environmental Agency, 2015)

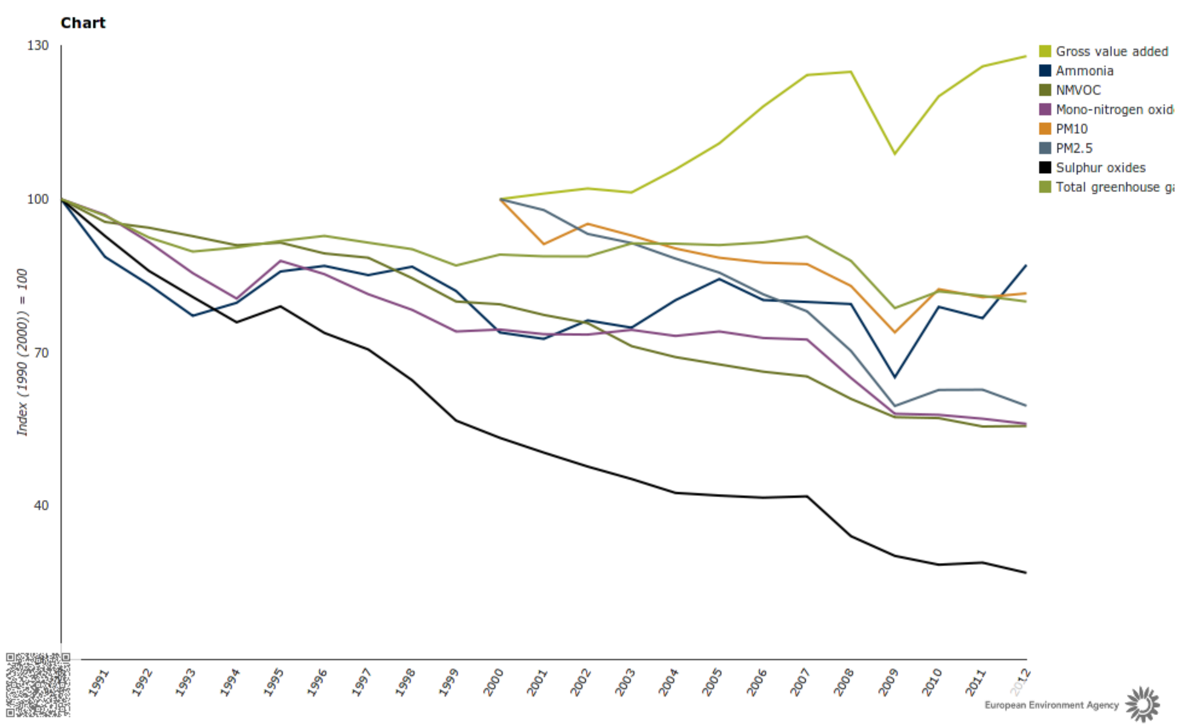

Figure 5: Emissions of Air Pollutants and Greenhouse Gases, and Gross Value Added from European Industry (European Environmental Agency, 2015)

As mentioned above, innovative pollution abatement technologies are a crucial factor in the strive to a greener and more sustainable future. Especially with respect to innovative technologies, the concept of Industry 4.0 is expected to, on the one hand, raise European industry to the next level in terms of global competitiveness and knowhow and, on the other hand, to continue and amplify the trend towards a greener manufacturing sector.

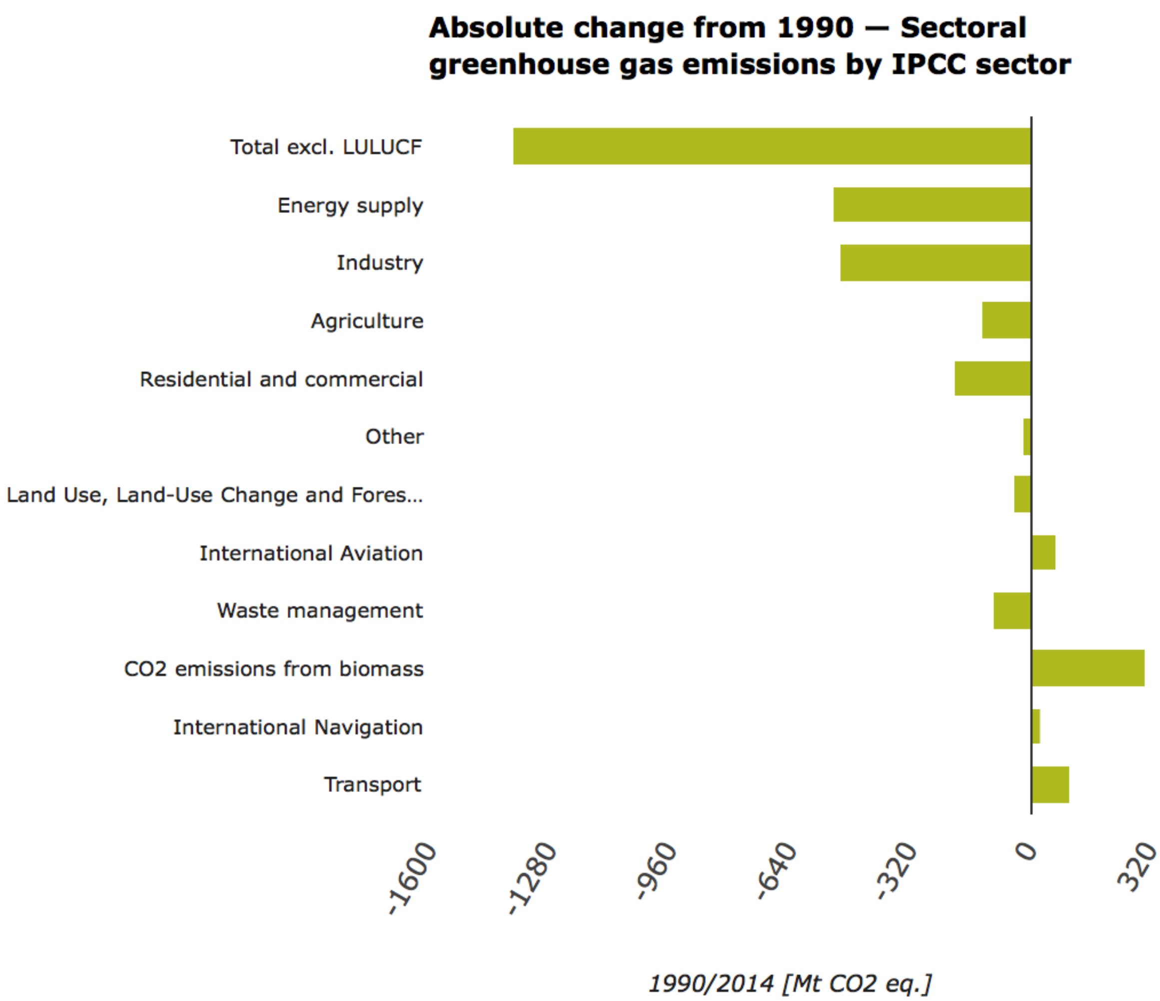

Figure 6: Absolute Change from 1990 - Sectoral Greenhouse Gas Emissions by IPCC Sector (European Environmental Agency, 2016)

Figure 6 illustrates the absolute change in greenhouse gas emissions between 1990 and 2004 in CO_2 equivalent. The total greenhouse gas emissions excluding land use, land-use change and forestry (LULUCF) decrease significantly since the year 1990. With respect to sectors, industry is second when it comes to reductions in greenhouse gasses. This strengthens the argument that the industrial sector already achieved some successes in decreasing greenhouse gas emissions. As mentioned before, one of the decisive factors is technological development and Industry 4.0 is capable of delivering exactly that. The energy supply sector is the only sector that in terms of greenhouse gas emission reductions performs better than the industrial. This enormous decrease in pollutants is only possible due to the fact that the energy sector is a major emitter. Otherwise, it would be impossible to cut that much.

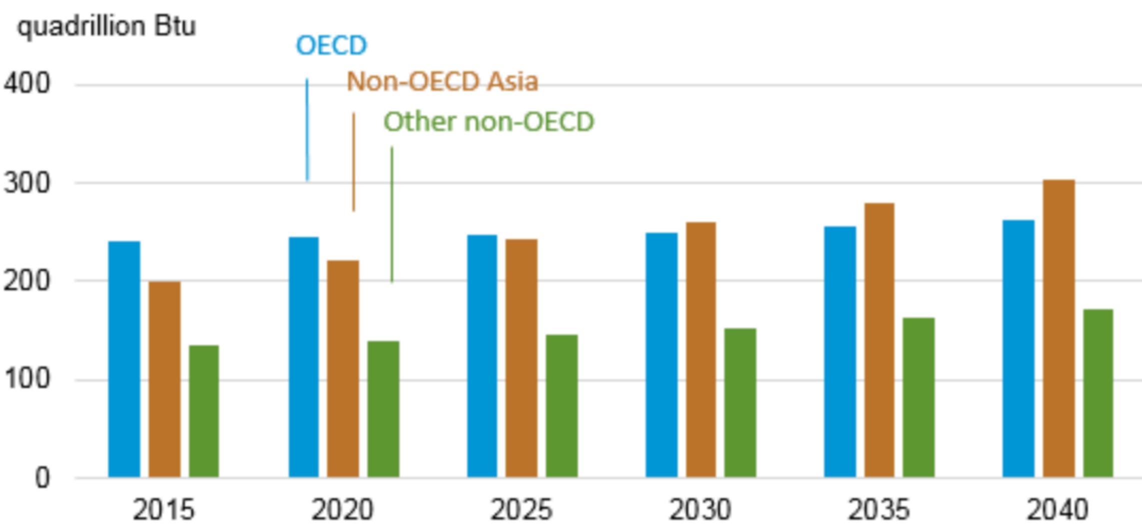

Figure 7: World Energy Consumption by Country Grouping (Energy Information Administration, 2017)

Figure 7 shows the global energy consumption as it is at the moment as well as a forecast up to the year 2040. All depicted groups of countries are expected to increase their demand for energy. Consequently, even though the energy supply sector is diminishing its greenhouse gas emissions in relative terms, a net increase in greenhouse gas emissions can be anticipated.

In the context of this, Figure 8 states the relationship between renewable and non-renewable sources of energy. The upper bar chart shows the relatively minor share of renewables compared to non-renewable and thus, emission-intense energy sources. The lower bar chart then shows that the largest share of renewable energy is coming from traditional uses of biomass such as agricultural by-products, wood fuels and dung. The issue with that is that biomass as a source of energy is a large greenhouse gas emitter itself. This can be seen in

Figure 6, showing CO_2 emissions from biomass as the sector with the strongest increase in greenhouse gas emissions since 1990.

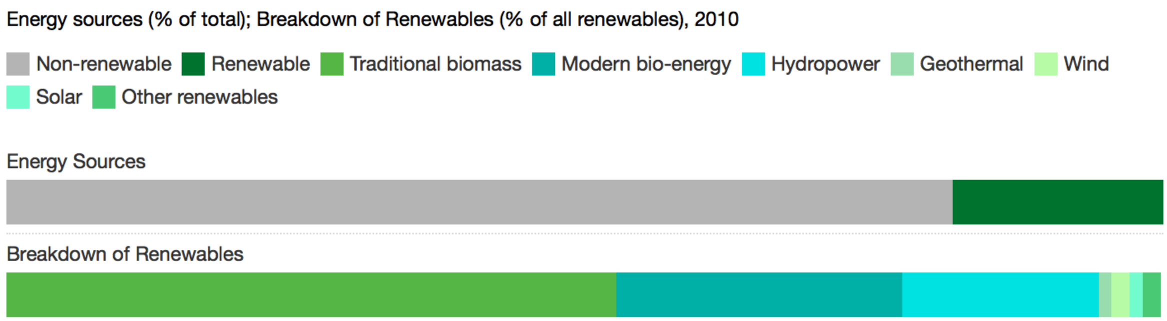

Figure 8: Renewable Energy Sources (Tabary and Purdie, 2010)

Having this in mind, it can be expected that the rise of Industry 4.0 and all its additional technical developments, tools and devices will only intensify this trend of increasing demand for energy and parallel to it an increase in greenhouse gas emissions. It is true that the purpose of most of these technologies is to improve efficiencies, including energy efficiency. However, the additional increase in demand for energy is more likely to be the change with the greater extent.

3.5 Reduced Use and Conservation of Resources

The number of raw materials and resources is decreasing at a fast pace due to the exploitation that took place especially over the past 200 years. The fact that they are already comparatively limited makes their extraction a more and more difficult and consequently more expensive task. Additionally, the current trend in the light of industrial products is that they are getting smaller, while, at the same time, becoming more and more complex in their composition. In many cases, it is not even clear out of what kind of materials a product consists. This undesirable trend asks for measures such as reuse of materials and new recycling technologies combined with complementary product-related information in order to raise awareness and, thereby, increase concern and importance regarding the appropriate handling of resources. (Garetti and Taisch, 2012)

Many proponents of Industry 4.0 name a reduction in costs together with an increase in resource efficiency as the major benefits coming from the transition to a networked and self-regulating production system. The resources that they refer to include raw materials, financial resources as well as consumables such as energy. Hence, I 4.0 will not only optimize the use of resources but also reduce production costs and increase productivity. Overall, this will contribute to a substantial gain in flexibility as well as a greener and more sustainable economy. The concept of I 4.0 is expected to contribute to improving resource efficiency in particular by minimizing expenditure of resources. Material costs, especially in the case of raw materials, make up about 40 per cent of the overall production costs. The application of CPS will enable case-by-case optimizations of materials used in the production process and, at the same time, makes a resource-conserving and efficient design of processes possible. Making the right decisions as well as finding a balanced position between what is technically feasible, economically viable and socially and environmentally acceptable is going to be one of the key challenges in the pursuit of the desired productivity and efficiency increase. (Aichholzer et al., 2015)

The most research in the light of reduced use and conservation of resources is related to topics such as new recycling technologies and material reuse, remanufacturing, sustainable packaging, etc.. (Garetti and Taisch, 2012)
In the following, the mentioned research areas are described in further detail.

3.5.1 New Recycling Technologies and Material Reuse

Returning waste materials into supply chains and using them as raw materials, energy sources or as substitutions for non-renewable natural resources are all initiatives that could easily be implemented under I 4.0 and that help reaching a more sustainable future. With regards to this, new efficient recycling and collecting technologies and processes that are ideally based on the concepts of reuse, further use, upgrading and remanufacturing are needed. (Dodbiba et al., 2008)
Due to the increasing number of materials used in products, their environmental impact when being disposed becomes more and more relevant. Hence, the development of a comprehensive life cycle methodology in order to optimize the life usage and the reuse capability of the product is needed for the reduction of their disposal impact. (Garetti and Taisch, 2012)

3.5.2 Remanufacturing

Remanufacturing is an area of research as well as a business area that becomes more and more important as countries are tightening environmental legislations and regulations in economic activities. The quality of reused products varies from product to product and might even change during the manufacturing process. Thus, the performance of the entire remanufacturing system can be enhanced by individually handling the used products depending on their dynamic quality. An optimization of remanufacturing processes leads to an increase in efficiency, which, in turn, allows for cost reductions as well as for the reuse of remanufactured components and, at the same time, satisfies required quality specifications. There is no doubt that this has the potential to substantially contribute to the usage optimization of natural resources as well as various raw materials. The technological developments that the concept of I 4.0 entails are expected to provide what is required for improving remanufacturing and, therefore, to help approaching more sustainable industrial standards. (Garetti and Taisch, 2012)

3.5.3 Sustainable Packaging

Sustainable packaging is an issue that is already on the rise. Many companies, especially in the consumables sector, looked into optimization of packaging with the intention of making it more sustainable while gaining additional economic value (e.g. via cost reduction). The packaging issue can be considered an area with sustainability potential, since it forms an essential part of wastes for industrial as well as consumer goods. (Garetti and Taisch, 2012)

3.6 Energy Savings

When taking a look at the various resources consumed by manufacturing, energy appears to be crucial regarding sustainable development. First and foremost, this is because of the impact of fossil fuels on the environment. The manufacturing sector is responsible for more than 36 per cent of the worldwide final energy consumption as well as for about the same percentage of direct and indirect global CO_2 emissions. Thus, the improvement of energy efficiency is a major stepping stone towards a more sustainable future. (IEA, 2017)

The digitalization of manufacturing processes is one of the key features of Industry 4.0 and has the potential to be transformed in such a way that energy can be saved. This can, for instance, be achieved by optimizing or replacing certain technologies, by applying new software tools or by adapting business processes. Generally, energy can be saved by an increase in energy efficiency. Over the past years, energy efficiency has indeed advanced. However, in order to achieve the international climate change mitigation targets, the improvement of energy efficiency has to continue. In particular the industrial sector comprises a tremendous potential in this respect. In order to realize this potential, technological developments and new technologies are necessary. Estimations depict that energy use could be cut by 13 to 29 per cent in the most energy-intensive industrial sectors (namely iron and steel, chemicals, cement, aluminum and pulp and paper) through the implementation of the best available technology (BAT). In turn, the reduction in these five sectors would lead to a reduction in global energy use and global CO_2 emissions by approximately 4 per cent. These numbers show the potential that an adequate implementation of Industry 4.0 implicates. (UNIDO, 2017)

An additional aspect that should at least briefly be mentioned in this context is renewable energy, since renewable energy and energy efficiency constitute the two central components of sustainable energy systems. These do not only play pivotal roles in achieving international climate mitigation and sustainable development targets but further, share important characteristics with the concept of Industry 4.0. Both, the sustainable energy transition as well as Industry 4.0, are strongly influenced by technological innovations, are dependent on the development of new appropriate regulations and infrastructures and are potential enablers for new business models. Despite this nexus, their shared features have not yet been translated into respective policies in order to concurrently emphasize more sustainable energy systems as well as digital production in an integrated manner. The share of electricity consumption of industries worldwide amounted 42.5 per cent in 2014 and energy networks have the duty to accommodate the electricity demand from these industrial consumers. Knowing this, one can easily imagine how the digital transformation of industries as well as the transition towards more sustainable energy systems could gain from one another. Further, it could help avoiding the development of new path dependencies, which might lead the energy sector as well as the industrial sector into a more carbon intense and less sustainable future. An integrated approach like this could be accompanied by the Sustainable Development Goals (SDGs), which supply important target settings concerning energy, climate action and beyond. (UNIDO, 2017)

The concept of Industry 4.0 brings with it several technological developments that inevitably lead to the establishment of so-called smart factories. Some characteristics of these digitalized, networked and interconnected factories have the potential to be more energy efficient and thus, to reduce pressure on the environment. The essential reason for the difficulties in evaluating and improving factories' energy efficiency is the lack of understanding of the energy consumption behavior. A solution to this is the comprehensive collection of data from smart meters, sensors as well as other tools and the integration of this data into production management in order to enhance energy efficiency. These aspects are all included in the IoT technology, which makes it capable of changing the conventional paradigm of energy measurement. Furthermore, remote monitoring of energy consumption data across the factory becomes possible by the application of sensors and smart meters. This data can then be used by energy management experts to make real time assessment. Overall, even more sustainable practices could be implemented based on the adoption of IoT technology for the improvement of energy efficiency at production level. For instance, the prevention of peak times, the integration of energy data in the production schedule, and so on. (Shrouf, Ordieres and Miragliotta, 2014)

4. Expert Opinion

In order to not only rely on the findings coming from existing literature, this chapter either proves or disproves the information generated by researching literature with personally conducted expert interviews. The experts that offered me their time and expertise are, on the one hand, DI Roland Sommer, MBA who is the CEO of the “Plattform Industrie 4.0 Österreich” and, on the other hand, Dr. Thomas Fleckl, who is the Head of Competence Unit Sustainable Thermal Energy Systems. In the case of Mr. Sommer, the interview was conducted in person on the 3rd of May 2018 in the Viennese office of “Plattform Industrie 4.0 Österreich”, while Dr. Fleckl answered the exact same questionnaire in a digital format on the 4th of May 2018. Every information stated in this chapter refers to the two questionnaires, unless another reference is explicitly mentioned. Both questionnaires can be found in Annex 1. The questionnaire consists of three chapters, with the first chapter consisting of five questions with a focus on Industry 4.0 in general as well as on the impact and goal of the respective expert’s institute. The focus of the second chapter is on the nexus between Industry 4.0 and the environment. With a total of six, in parts sophisticated questions, this is the chapter where the main emphasize is put on. The last chapter does not consist of any questions but firstly, gives the interview partner the chance to state any additional information that has not been covered by the two previous chapters and secondly, provides space for any follow up comments or references.

4.1 Concerning Industry 4.0 in General

The first question of chapter one asked for a definition of Industry 4.0. The main idea behind this very general question was to have a smooth start into the interview as well as to hear a definition of this rather complex and comprehensive concept of Industry 4.0 from an expert that actually has to do with this issue in day-to-day life and compare it to the most prominent and valuable definitions that literature offers. Sommer claims that for him Industry 4.0 can be defined as the vertical and horizontal integration as well as the digitalization of the value chain. Industry 4.0 is a political buzz word that encompasses various sectors and areas such as manufacturing, services, new business models, etc.. Due to the terms eclectic character, many people do not really know what it actually is about. Some companies that invest a lot of money into the implementation of Industry 4.0 technologies claim that they are only at the very beginning, while others argue that they are 100 per cent digitalized because of the fact that they have an homepage. These two very controversial statements are a nice example

to show how extremely substantial and intangible the term and the concept underlying Industry 4.0 is.
Fleckl defines the term Industry 4.0 as the full interconnection of industrial manufacturing which is characterized by a high degree of automatization both regarding the processes and regarding the level of interconnection and which further keeps the newly generated knowledge within the system in order to build upon it.

The follow up question focuses on the role and aim of the institute of the respective expert and, thus, on the added value that they create in the light of Industry 4.0. Fleckl works for the Austrian Institute of Technology (AIT), which is an applied research institute that develops solutions and technologies in the various sectors for the industry as well as in cooperation with the industry. Regarding Industry 4.0, these developments aim, amongst others, at the areas of digital safety and security, energy, mobility, visualization, automatization and regulation, interface between human and machine as well as the development of new production technologies.
In the case of Sommer's "Plattform Industrie 4.0 Österreich", the field of tasks can be divided into four main areas. Improving the political framework conditions regarding digitalization with a focus on manufacturing companies, supporting Austrian businesses in the manufacturing industry, coordinating interests between the various players, as well as in a general sense thinking ahead and addressing topics that might be of relevance for the manufacturing industry in Austria.
All in all, the job of both institutions is to support the Austrian manufacturing industry in their endeavor to implement various technologies as well as other aspects belonging to the concept of Industry 4.0 and thereby, to remain competitive. In the case of the AIT, it appears that the general focus rather lies on technological development and consulting, while in the case of "Plattform Industrie 4.0 Österreich", besides the technological dimension the focus appears to be on consulting and supporting with respect to the political dimension.

The two upcoming questions targeted the most prominent benefits as well as the major challenges coming with Industry 4.0. The answers of the two interviewed experts look somewhat similar with only marginal differences. First and foremost, Industry 4.0 obviously has to constitute a benefit for the implementor compared to the state-of-the-art. If this is not the case, an implementation of Industry 4.0 technologies is unrewarding. The benefits entailed by an implementation of Industry 4.0 can be legion. According to both experts, the most prominent benefits of Industry 4.0 refer to manufacturing itself. One major vision in this regard is called batch size one. This means to produce customized products at mass production costs. Obviously, this is not realistic for all manufacturing industries but for those applicable, it is desirable. In order to have an idea what this means, Sommer names an example. Siemens has a plant in Amberg in Germany, where they have one production line with which they are capable of manufacturing around 250,000 different product variants. Also referring to manufacturing is predictive maintenance. That means that machines will tell when maintenance is due. The consequent advantages are a significant reduction in downtimes, improvement of production quality, increase in energy and resource efficiency as well as a reduction in costs. Connected to the improvement of production quality is the new quality requirement. In the past, an incoming and dispatch control was sufficient. Already nowadays and especially with Industry 4.0, almost every production stage comprises sensors for controlling. The advantage is that as soon as something gets out of hand, production stops and, hence, rejects can be minimized. Besides the various monetary advantages, this also entails environmental advantages, since it leads to a reduced and more reasonable usage of raw materials. Further beneficiary aspects concerning manufacturing are the automatization of repetitive tasks, the application of new manufacturing processes, the retention of knowledge and expert knowledge in models and the generation of new knowledge out of it ("machine learning").

Another area where benefits coming from Industry 4.0 are expected is the massive change in business models. For instance, data collection, processing and analysis is a promising area. By reference to Tesla, one application, with, amongst others, also positive environmental impacts is the configuration of existing products via software updates, meaning the adjustment of the settings of the respective car according to its respective owner. Further, not only structured but also unstructured data can be used. An example would be the tapping of unstructured data for social media platforms and its integration into logistics planning, e.g. someone posting that there is traffic on the highway and a logistics company using this information to plan an alternative route.

However, especially the business models that have to do with the enormous amounts of newly acquired data and know-how do only function under the premise that confidentiality is ensured. Consequently, the systems in the background have to meet certain standards concerning aspects such as IT security. One aspect that is gaining importance in the light of this is whether manufacturing machines can be hacked. So far, this question has not really been an issue but since manufacturing machines' technology is going to be online as well as interconnected under Industry 4.0, the protection and safety of the data and know-how obtained in the manufacturing processes as well as in the course of all other business processes and services has to be ensured. Besides the safety aspect, Fleckl argues that the newly acquired data and know-how has to be interpreted and employed appropriately. In order to guarantee this, cooperation with expert knowledge is important.

In general, one of the most prominent challenges coming with Industry 4.0 is to realize and understand potential advantages and to implement the necessary technological and structural changes needed to actually benefit. Fleckl points out that in many sectors, the added value of the various new developments is not yet distinct. Further, different regions face different challenges. And this does not only apply on a worldwide scale comparing the challenges of e.g. Europe, China and the U.S. but also on a smaller scale. For instance, within Europe a country such as Spain will face different challenges than countries like Germany or Austria with a comparably rather high industrial rate. This shows the next type of challenge, namely technology. Depending on the status quo, it is even impossible to compare national challenges. In this regard, on has to separate sectors and industries. Ideally, even every single company has to be considered individually. Another challenge refers to the social sphere. With an increase in automatization and technology, the working environment is expected to change drastically. Consequently, the qualifications that workforce has to provide will change as well. However, in the context of this, Sommer expects that these changes will not lead to a wave of redundancies in countries such as Austria, where standards in the manufacturing industry are already high in global comparison. His forecast predicts that more white collar than blue collar jobs will be cut. This is because new technologies can replace employees in areas such as accounting, while the high rate of automatization and digitalization coming with the sophisticated technologies in the manufacturing process asks for qualified personal able to cope with it. Both experts agree that an aspect of outmost importance in this respect is the provision of adequate training and education. A challenge that Sommer explicitly mentioned refers to the new arising business models. This is expected to be a particular challenge for Europe and the German-speaking world, because of the fact that they are outstandingly endowed with engineering and manufacturing of technologically complex products and solutions. As an example to attest this argument, the comparison of Tesla and Mercedes was mentioned. When comparing the cars produced by the two manufacturers, a Mercedes can be characterized as a technologically more sophisticated car than a Tesla. However, Tesla offers a business model that can compete with that of Mercedes. This shall depict that it is not exclusively about ingenious technological solutions but about the overall package, and with regard to the development and coverage of new business models, there is some room for improvement.

The last question of chapter one refers to the stage of implementation in which Industry 4.0 currently is and to sectors which act as role models. Again, the answers of both experts were basically the same with only minor differences. This shows the value and validity of the received answers. Fleckl as well as Sommer argued that coverage as well as degree of maturity differ significantly amongst the various sectors. However, if one would have to name a pioneer than this would be the manufacturing sector, even though there are obviously also companies in the manufacturing industry that cannot be regarded as role models, while there are pioneer companies in other sectors.
Sommer names the automotive sector as another example for a sector in which the concept of Industry 4.0 is a major issue and already advanced. As an example to illustrate this argument, he mentioned the customization options to configurate cars in many different ways, which requires extremely flexible production processes.
Fleckl mentions the construction industry as a rather rudimentary one. Yet, integrated planning, constructing and operating is more and more becoming a necessity in the construction branch. In general, he argued that in most cases the added value of e.g. interconnectivity and other changes coming with Industry 4.0 first have to be discerned and proven. Most facilities are designed for efficient but not for flexible production processes and before making an investment and implementing new technologies, businesses want to have proof that a change is necessary and useful. Generally talking about the stage of implementation of Industry 4.0 and the respective preconditions, Sommer claims that the apprenticeship training is an advantage with respect to Industry 4.0 for the manufacturing industry in the German-speaking world. This is because of the fact that apprentices are trained in such a way that they become highly educated employees with the ability to more easily adapt to constantly or significantly changing working conditions compared to less qualified employees.

4.2 Concerning Industry 4.0 with a Focus on the Environment

Due to the correlation between the first and the third question of chapter two, question 2.2 is the one elaborated first. The intention behind question two of chapter two is to figure out whether there exists something like a “Sustainable Industry 4.0” concept. Both experts claimed that they have not heard of an explicitly sustainable concept of Industry 4.0 by now. In fact, sustainability is a part of the concept of Industry 4.0. However, hardly any company started implementing or is going to implement Industry 4.0 primarily due to sustainability reasons. The fact that higher standards regarding sustainability comes with the implementation of Industry 4.0 is a positive connotation but cannot be seen as the reason for implementing the concept of Industry 4.0.

The intention of the first question of chapter two is to elaborate whether there exists a nexus between Industry 4.0 and the environment. Yet again, both experts agreed that there is an occasionally strong connection between the concept Industry 4.0 and the environment. Fleckl suggests that there would be a strong connection regarding energy efficiency as well as regarding the application of fluctuating renewable sources of energy. Overall, Industry 4.0 has the potential to optimize the resource use (regarding raw materials, energy, waste and emissions) in the production process. However, this might possibly lead to conflicts with other aims of Industry 4.0 such as batch size one or a flexible production.
Sommer links answering this question with question 2.3, which asks for the most prominent positive as well as negative changes concerning the environment that Industry 4.0 entails. He said that one can only manage what one can measure, meaning that only given that the energy demand is known, changes can be made and behavior can be adopted. As an example he mentioned an experiment by students at ETH Zurich. They were asked about their demand for water (in liters) when taking a shower. Their assumptions were much lower than the actual result and the consequence was that they drastically reduced their demand (in liters). Visualization led to change in behavior, and this is what can be expected from the implementation of Industry 4.0 regarding positive effects on the environment. Another positive impact on the environment results from the increase in quality control, which is expected to take place at almost all production steps. Consequently, the number of rejects will be reduced severely. Sommer refers to statistics showing that human beings make between 500 and 600 mistakes per 10,000 tasks. This rate is expected to drop to eight to ten mistakes per 10,000 tasks under the concept of Industry 4.0. This increase in efficiency also leads to the result that the same amount of output can be produced with less input,

which results in a reduction in the need for raw materials. Further, a technological novelty that is related to Industry 4.0 is the concept of the digital twin. The general idea behind this is to not only virtually develop prototypes before constructing them but to also simulate the coveted functions and processes. Only under the premise that the simulation of the construction and operation of the prototype is perfect, the plan is put into action. The result is going to be a massive conservation of resources. Another new technology with an enormous potential regarding the conservation of resources is 3D printing. The major advantage of this is that it only uses exactly the amount of material required and that it does not produce any waste. Also the digitalization per se can be seen as a positive effect on the environment. It is true that it might lead to an increase in the demand for energy, but many products that once had to be manufactured and therefore, required raw materials are nowadays mostly available in digital form. An example would be the music industry. In the past, one had to produce CDs or records and today streaming platforms and music portals increasingly gain importance.

In addition to that, Fleckl provides some more positive effects on the environment coming from Industry 4.0. The ability to identify potential failures, breakdown etc. at an early stage results in temporal, economical as well as advantages regarding resource (energy) conservation. Furthermore, purposeful maintenance, more efficient use of resources and the fact that newly acquired knowledge can be kept in the system were also mentioned as positive aspects that an implementation of Industry 4.0 entails.

All in all, both experts agreed that the most prominent positive effects on the environment coming from Industry 4.0 are the increase in efficiency e.g. coming from a higher degree in occupancy rates, and the more efficient usage of resources, e.g. due to less waste, rejects and energy demand. Both leads to a conservation of resources compared to status quo.

Frankly, the advance of Industry 4.0 might also have negative effects on the environment. Fleckl argues that with an increase in automatization, production can become cheaper while capacity can augment. Thus, businesses might want to use this opportunities, which consequently does not lead to more sustainable and durable products. Also, batch size one might be economically unreasonable compared to mass production and as such not an objective to pursue.

Sommer states that the additional technology leads to an increase in energy demand. Actually, the expected increases in efficiency result in a reduction in demand for energy. However, all the additional technologies and devices demand a lot of energy. Technologies such as blockchain or just the collection, analysis and storage of data require a substantial additional amount of energy. Consequently, it is not sure yet but it could well be that the overall energy demand increases. In order to cover the additional demand for energy adequately, meaning ideally with energy coming from renewable sources and not from fossil fuels, a comprehensive infrastructure program is necessary. For this, the public sector is in demand.

The intention of the fourth question of chapter two is to find out the potential of aspects such as increasing transparency, illustration of data (e.g. real-time emission data), etc. that come with Industry 4.0 regarding the environment. Fleckl argues that data necessarily have to be linked with an appropriate interpretation in order to prevent unwanted misconceptions (for instance an exceedance of emission limits during the boot of a machine). Real-time data can be used concerning surveillance. Data about products such as CO_2 imprint, origin or required resources could in general be valuable for consumers in the buyer decision process and therefore, be beneficiary for sustainability.
Sommer focused on an argument that he already made in the course of answering another question, namely that visualization has the potential to lead to a change in behavior. With respect to this very question, he argues that an increase in transparency and illustration of data raises awareness and consequently, leads to more sustainable behavior. In order to undermine this argument, he cited an example from a project in supermarkets in Ireland. The various stores had completely different demands for energy with the reason for it being unknown. After a while, it was discovered that the temperatures in the freezers were significantly different. In some stores the demand for energy was 50 per cent more than in other stores, only due to the different temperatures in the freezers. The measurement and collection of data led to an increase in transparency and thus, to the realization that there is an enormous potential for energy conservation. Due to the fact that one measured and illustrated data, a change in behavior has been considered. Furthermore, cameras were installed in the parking area and when a certain amount of cars entered the parking area, the temperature in the freezers were automatically reduced because one knew that the amount of opening and closing activities in the store would increase within the next minutes. The results were a reduction in costs for energy, an increase in efficiency and consequently, an improvement in the conservation of resources.

Question 2.5 refers to the necessity of changes in legislation in order to be able to profit from potential benefits for the environment coming with the implementation of Industry 4.0. Both experts agree that it will be inevitable to have certain legal adaptions due to the fundamental changes that Industry 4.0 entails.
Besides the legal framework conditions, Sommer campaigns for political tools and initiatives to motivate companies. According to Sommer, such political instruments might be more appropriate to accomplish change. Businesses should have an intrinsic motivation to act, rather than being forced by law. Therefore, the public sector is, on the one hand, in demand. On the other hand, it possesses a lot of potential for change. A government, for instance, can emphasize a topic by putting the focus on it (e.g. by mentioning it in a government program). In Austria, the term digitalization is mentioned 89 times in the government program of 2018.

The last question of chapter 2 focuses on the consciously sustainable implementation of Industry 4.0. Sommer states that an increase in efficiency and a more efficient utilization of resources mostly result in a reduction in costs, which depicts the actual prime motive. Companies gladly acquiesce that the implementation of Industry 4.0 has positive effects on the environment. However, the chances of a company implementing Industry 4.0 due to sustainability reasons are almost zero. Yet, one has to be careful with this statement. As elaborated in paragraph 3.2, sustainability does not only have an environmental but also a social, economic and arguably even a technological dimension. Industry 4.0 might not exclusively be implemented due to the environmental, but for the social dimension. In this respect, Industry 4.0 offers a number of excellent opportunities. For instance, projects that equip people with disabilities with digital assistance systems, which allow them to integrate into manufacturing processes and thereby, gives them the chance to find a job.
According to Fleckl, it is rather the other way round than what the question suggests, namely that the implementation of Industry 4.0 results in a conservation of resources. In a broader sense, an example in this regard would be the implementation of direct electricity trading via blockchain between the producers (PV) and the consumers in New York.

5. Foresight and Results

Our modern world faces a number of great challenges. One of those challenges is that nowadays economy is locked into a system where the linear model of production and consumption is still favored by many. However, this lock-in is decreasing under the pressure coming from the emergence of some disruptive trends. The key characteristic that all of these disruptive trends share is advanced information technology, which is considered to be able to provide the required qualities and characteristics. With particular respect to the manufacturing industry, the concept of Industry 4.0 is this promising disruptive trend. System thinking skills combined with a comprehensive and integrated understanding of technology and data will be decisive in the approach to overcome the difficult environmental, economic and social challenges of today and tomorrow. Industry 4.0 technologies and its smart products are expected to not only meet these challenges but to further even generate substantial economic, social and environmental benefits. Hence, it has the ability to contribute to the strive towards a circular economy (CE). The economic system that follows the concept of a CE will be able to lead to a new time of development and growth, which represents a promising opportunity to redefine the nexus of the present economy with resources and to create a socially, environmentally and economically sustainable future. (Blunck and Werthmann, 2017)

This master thesis aimed at finding a science based answer to the research question what the most prominent positive as well as negative effects on the environment entailed by Industry 4.0 are. In the course of elaborating and exploring the existing literature as well as by conducting interviews with two respected experts, an adequate answer including the presumably major positive as well as negative effects on the environment appears to be found.

When combining the findings coming from the conducted literature review with the expert findings, the most prominent negative effect on the environment that the implementation of Industry 4.0 entails in the increase in energy demand. At the center of the concept of Industry 4.0 are a number of highly sophisticated and promising technologies that are obviously powered by electricity. Installing additional technologies and technical devices necessarily requires additional energy. Since the share of renewable energy is still minor compared to energy coming from fossil fuels, an increase in energy demand is expected to lead to an increase in the negative externalities of fossil fuel energy, such as augmenting CO_2 emissions etc.. The result is an extra burden for the environment.

Concerning the most prominent positive effects, two major benefits can explicitly be mentioned. Having in mind the major negative effect, the first benefit might sound sarcastic, but energy savings coming with the new Industry 4.0 technologies is one of the major benefits. The increase in efficiency and transparency leads to more efficient production processes and thereby, to a reduction in energy consumption. As mentioned above, it is true that these new technologies require an additional amount of energy but one of their main purposes is to increase efficiencies and with that, reduce the demand for energy in the different production phases. It is not yet determined whether the overall energy demand will increase or decrease compared to the current situation. Frankly, forecasts predict that a rise in energy consumption is more likely.
The second major positive effect for the environment is the reduced use and conservation of resources. The increase in resource efficiency is a result of the overall increase in efficiencies of the production processes. In turn, having more precise processes results in a situation in which the same amount of output can be made from less input. Thus, the expected increase in productivity together with the optimization in the use of resources will, on the one hand, contribute to flexibility gains and, on the other hand, to a more environmentally-friendly economy.

The future of Industry 4.0 in general looks promising. It entails a number of advantages that, from an economic, social and environmental point of view, make sense to desire. Implementing Industry 4.0 of course also brings with it some serious challenges. However, all these challenges can become beneficiary when mastering them. The motivation to implement Industry 4.0 will in almost all of the cases be an economic rather than an environmental one. But since Industry 4.0 entails a number of benefits that have an overall positive effect on the environment, this development and fourth industrial revolution can, from an environmental point of view, only be endorsed.

References

Aichholzer, G., Rhomberg, W., Gudowsky, N., Saurwein, F. and Weber, M., 2015. *Industry 4.0 – Background Paper in the pilot project "Industry 4.0: Foresight & Technology Assessment on the social dimension of the next industrial revolution"*. [pdf] Austrian Academy of Sciences. Available at: <http://www.austriaca.at/ita/ita-projektberichte/ITA-AIT-1en.pdf> [Accessed 05 April 2018].

Baud, R., 2008. *The Concept of Sustainable Development: Aspects and their consequences from a social-philosophical perspective*. [online] Available at: <https://de.scribd.com/document/6527163/Concept-Sustainability-Dr-Roger-Baud-YES> [Accessed 15 April 2018].

Bauernhansl, T., 2014. *Die Vierte Industrielle Revolution – Der Weg in ein wertschaffendes Produktionsparadigma* in Bauernhansl, T., ten Hompel, M. and Vogel-Heuser, B., 2004. Industrie 4.0 in Produktion, Automatisierung und Logistik. Wiesbaden: Springer Vieweg, pp. 5-34.

Blanchet, M., Rinn, T., Von Thaden, G. and De Thieulloy, G., 2014. *Industry 4.0: The new industrial revolution – How Europe will succeed.* [pdf] Roland Berger Strategy Consultants. Available at: <http://www.iberglobal.com/files/Roland_Berger_Industry.pdf> [Accessed 10 April 2018].

Blunck, E. and Werthmann, H., 2017. Industry 4.0 – An Opportunity to Realize Sustainable Manufacturing and Its Potential for a Circular Economy. *Dubrovnik International Economic Meeting*, 3 (1), pp. 644-666.

Braungart, M. and Donough, W., 2008. *Die nächste industrielle Revolution. Die Cradle to Cradle Community*. Hamburg: Europäische Verlagsanstalt.

Brenner, L., 2018. Positive Effects of Humans on the Ecosystem. [online] Available at: <https://sciencing.com/positive-effects-humans-ecosystem-5869462.html> [Accessed 24 May 2018].

Busch, J., Soukup, A., Dutzler, H., Loinig, M. and Gorholt, A., 2015*. Industrie 4.0 – Österreichs Industrie im Wandel.* [pdf] PwC. Available at: <https://www.pwc.at/de/publikationen/industrie-4-0-oesterreichs-industrie-im-wandel-2015.pdf> [Accessed 10 April 2018].

Cleverism, 2017. *Industry 4.0: Definition, Design Principles, Challenges, and the Future of Employment.* [online] Available at: <https://www.cleverism.com/industry-4-0/> [Accessed 10 April 2018].

Dodbiba, G., Takahashi, K., Sadaki, J. and Fujita, T., 2008. The recycling of plastic wastes from discarded TV sets: comparing energy recovery with mechanical recycling in the context of life cycle assessment. *Journal of Cleaner Production*, 16 (4), pp. 458-470.

Energy Information Administration, 2017. *International Energy Outlook 2017*. [online] Available at: <https://www.eia.gov/outlooks/ieo/exec_summ.php> [Accessed 30 May 2018].

Erol, S., 2016. *Where is the Green in industry 4.0? or How Information Systems can play a role in creating Intelligent and Sustainable Production Systems of the Future.* [online] Available at: <https://www.researchgate.net/publication/318645767_Where_is_the_Green_in_Industry_40_or_How_Information_Systems_can_play_a_role_in_creating_Intelligent_and_Sustainable_Production_Systems_of_the_Future> [Accessed 14 April 2018].

European Commission, 1976. Draft Council resolution on the continuation and implementation of a European Community policy and Action Programme on the Environment. *Official Journal of the European Communities*, C115 Vol. 19.

European Environmental Agency, 2015. *Industry.* [online] Available at: <https://www.eea.europa.eu/soer-2015/europe/industry> [Accessed 30 May 2018].

European Environmental Agency, 2016. *Sectoral greenhouse gas emissions by IPCC sector.* [online] Available at: <https://www.eea.europa.eu/data-and-maps/daviz/change-of-co2-eq-emissions-2#tab-based-on-linked-open-data> [Accessed 30 May 2018].

Garetti, M. and Taisch, M., 2012. Sustainable manufacturing: trends and research challenges. *Production Planning & Control*, 23 (2-3), pp. 83-104.

Goudie, A., 2006. *The human impact on the natural environment: past, present, and future*. 6.ed. Malden: Blackwell.

Green Alliance, 2018. *Industry 4.0*. [online] Available at: <https://www.green-alliance.org.uk/tech_task_force.php> [Accessed 14 April 2018].

Helbing, D., 2015. *Societal, Economic, Ethical and Legal Challenges of the Digital Revolution: From Big Data to Deep Learning, Artificial Intelligence, and Manipulative Technologies*. [online] Available at: <https://arxiv.org/ftp/arxiv/papers/1504/1504.03751.pdf> [Accessed 11 April 2018].

IEA, 2017. *World Energy Outlook 2017*. [online] Available at: <http://www.iea.org/weo2017/> [Accessed 18 April 2018].

i-Scoop, 2017. *Industry 4.0: the fourth industrial revolution – guide to Industrie 4.0*. [online] Available at: <https://www.i-scoop.eu/industry-4-0/#The_origins_of_Industrie_40> [Accessed 08 April 2018].

Kagermann, H., Wahlster, W. and Helbig, J., 2013. *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*. [pdf] Forschungsunion. Available at: <http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf> [Accessed 05 April 2018].

MacDonald, P. 2016. *Future trends in engineering: global urbanisation and the fourth industrial revolution*. [online] Available at: <http://www.engineersjournal.ie/2016/06/14/future-trends-in-engineering-global-urbanisation-the-fourth-industrial-revolution/> [Accessed 24 May 2018].

McKinsey, 2012. *Manufacturing the future: The next era of global growth and innovation*. [pdf] McKinsey Global Institute. Available at: <https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/The%20future%20of%20manufacturing/MGI_%20Manufacturing_Full%20report_Nov%202012.ashx> [Accessed 06 April 2018].

OECD, 2015. *Data-Driven Innovation: Big Data for growth and Well-being. [pdf] Organization for Economic Cooperation and Development*. Available at: <https://read.oecd-ilibrary.org/science-and-technology/data-driven-innovation_9789264229358-en#page1> [Accessed 11 April 2018].

Pacala, S. and Socolow, R., 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, 305 (5686), pp. 968-972.

Roth, A., 2015. *Einführung und Umsetzung von Industrie 4.0: Grundlagen, Vorgehensmodell und Use Cases aus der Praxis*. Berlin: Springer Gabler.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M., 2015. *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. [pdf] The Boston Consulting Group. Available at: <https://www.zvw.de/media.media.72e472fb-1698-4a15-8858-344351c8902f.original.pdf> [Accessed 10 April 2018].

Schlick, J., Stephan, P., Loskyll, M. and Lappe, D., 2014. *Industrie 4.0 in der praktischen Anwendung* in Bauernhansl, T., ten Hompel, M. and Vogel-Heuser, B., 2004. Industrie 4.0 in Produktion, Automatisierung und Logistik. Wiesbaden: Springer Vieweg, pp. 57-84.

Schrauf, S. and Berttram, P., 2016. Industry 4.0: *How digitalization makes the supply chain more efficient, agile, and customer-focused*. [pdf] strategy&. Available at: <https://www.strategyand.pwc.com/media/file/Industry4.0.pdf> [Accessed 09 April 2018].

Shrouf, F., Ordieres, J. and Miragliotta, G., 2014. *Smart Factories in Industry 4.0: A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm*. [online] Available at: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7058728> [Accessed 19 April 2018].

Smith, A., Anderson, J. and Rainie, L., 2014. *AI, Robotics, and the Future of Jobs*. [pdf] Pew Research Center. Available at: <http://assets.pewresearch.org/wp-content/uploads/sites/14/2014/08/Future-of-AI-Robotics-and-Jobs.pdf> [Accessed 11 April 2018].

Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T. and Schlund, S., 2013. *Produktionsarbeit der Zukunft – Industrie 4.0. [pdf] Fraunhofer-Institut für Arbeitswirtschaft und Organisation*. Available at: <https://www.iao.fraunhofer.de/lang-de/images/iao-news/produktionsarbeit-der-zukunft.pdf> [Accessed 11 April 2018].

Stock, T. and Seliger, G., 2016. Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP*, 40 (2016), pp. 536-541.

Tabary, M. E. and Purdie, E. 2010. Sustainable development and the demand for energy. [online] The World Bank. Available at: <https://blogs.worldbank.org/opendata/sustainable-development-and-demand-energy> [Accessed 30 May 2018].

UN General Assembly, *Report of the United Nations Conference on the Human Environment*, 15 December 1972, A/RES/2994. Available at: <http://www.refworld.org/docid/3b00f1c840.html> [Accessed 23 May 2018].

UNIDO, 2017. *Accelerating clean energy through Industry 4.0: Manufacturing the next revolution.* [pdf] United Nations Industrial Development Organization. Available at: <https://www.unido.org/sites/default/files/2017-08/REPORT_Accelerating_clean_energy_through_Industry_4.0.Final_0.pdf> [Accessed 09 April 2018].

Zhang, G. J., Cai, M. and Hu, A., 2013. Energy consumption and the unexplained winter warming over northern Asia and North America. *Nature Climate Change*, 3 (5), pp. 466-70.

List of Figures

Annex

Annex 1

David Uecker

david.uecker@da-vienna.at

May 2018

TU WIEN CONTINUING EDUCATION CENTER

Questionnaire for MSc Thesis

Industry 4.0 and its Effects on the Environment

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

Interview #B

Place, Date: Wien, 03.05.2018

Institution: Plattform Industrie 4.0

Interview partner: DI Roland Sommer, MBA

Role: CEO of Plattform Industrie 4.0

1. General Questions

1.1 How would you define Industry 4.0? / Wie würden Sie Industrie 4.0 definieren?

horizontal + ~~vertikale~~ vertikale Integration d. Wertschöpfungskette und um die Digitalisierung dieser. I4.0 umfasst Prod., genauso wie neue GM, Services, etc. / I 4.0 ein pol. geprägter Begriff

Allgemein merkt man das viele eine andere Vorstellung von I4.0 haben: manche Unt. investieren viel u. sagen sie sind ganz am Anfang u. andere sagen sie sind zu 100% digitalisiert weil sie eine Homepage haben → Beispiel dafür, dass I4.0 ein schwer greifbarer und extrem umfangreicher Begriff

(GM = Geschäftsmodelle)

Mediatorrolle

1.2 What is the role and aim of your institute? / Welche Rolle nimmt Ihr Institut ein und was ist Ihr Ziel?

Plattform I.40 = Verein mit 6 Gründungsmitgliedern
- 1 Ministerium
- 3 Arbeitgeberverbände
- 2 Arbeitnehmerverbände

Funktion/Ziel: ① Koordinationsfunktion zw. Playern auf Bundesebene, zw. Bund + Bundesländern und jetzt auch int. hinsichtl. EU ein Schwerpunkt

② Verbesserung d. pol. Rahmenbed. hins. Digitalisierung mit Fokus auf Prod.-ind. auf Bundes-, Länder als auch EU-ebene.

③ Unterstützung der öst. Ind. im prod.-Bereich → da diese vor einer Reihe an Herausforderungen stehen e.g. Datasecurity, ROI, technologische Schwierigkeiten, MA haben Angst vor Veränd., ...
(prod.-erzeugenden)

④ generelles vorausdenken u. adressieren von Themen mit mögl. Relevanz, e.g. Crowdworking, Plattform basiertes Arbeiten, ... hat das Relevanz für prod. Ind.?
zB. Rückgang d. körperl. anstr. Arbeiten da dies Roboter machen, aber zunahme der psych. Belastung da man rund um die Uhr abrufbar sein muss

→ 45 Mitglieder stand Frühjahr '18: Unt., Forschungseinrichtungen (TU), Ministerien, AMS, ...

David Uecker

david.uecker@da-vienna.at

May 2018

TU WIEN CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

Potenziale + Herausf. gehen Hand in Hand / was ein Pot. abzuschöpfen muss eine Herausf. bewältigen werden

1.3 What would you say are the most prominent benefits of Industry 4.0? / Was sind Ihrer Meinung nach die größten Potenziale von Industrie 4.0?

→ Prod. selber/an sich → Vision: Losgröße 1 zu Kosten wie Massenprod. → nicht in allen Bereichen realisierbar, aber im Allgemeinen die Bestrebung

1 → Losgröße 1 heißt starke Individualisierung, zB Magna: jedes 6.000ste Fahrzeug im Grazer Werk ist ident, zB. Siemens Werk in Amberg, GER: eine Prod. Linie kann 250.000 Prod.varianten fertigen (Simatik-, Elektronikbauteile) — Potenziale im Prod. Bereich

2 → realtime Einbindung d. Kunden bestimmen

3 → predictive maintenance → Maschinen sagen wann sie gewartet werden möchten → Red. der Stillstandszeiten

→ massive Veränd. bei GMs e.g. something as a service, pay per use, ..

4 Zusatz zu Prod.: ganz neue Qualitätsforderung in Prod. → früher Ein- u. Ausgangskontrolle, mittlerweile: Kontrolle bei jedem Prod.schritt → (Sensoren billig) → daher kann man Ausschuss frühzeitig sagen, dass etwas aus dem Ruder läuft u. Prod. wird gestoppt → Red. von [illegible] — pos. für Umwelt

→ Datenerhebungen, welche auch zu pos. Umweltauswirkungen führen zB Tesla: durch Software updates bereits bestehende Prod. konfigurieren

1.4 What would you say are the major challenges coming with Industry 4.0? / Was sind Ihrer Meinung nach die größten Herausforderungen, die Industrie 4.0 mit sich bringt?

Daten können zum einen sehr strukturiert als auch un-- sein → viele von Nutzen. Unstr.: Twitter od. FB "Stehe im Stau" → abgreifen dieser Daten u. in Logistikplanung mit aufnehmen

→ viele der GM funktionieren zB. hinsichtl. Daten nur wenn Vertraulichkeit dieser gesichert ist, heißt die Systeme die dahinter stehen müssen sicher sein (IT security)

→ immer öfter gestellte Frage: können Prod. maschinen gehackt werden? → war bislang kein Thema! → Security im Prod. Prozess sowie hinsichtl. Services wichtig! / von Daten

→ für Europa u. insbesondere für deutschspr. Raum sind die neuen GM eine Herausf. weil sehr gut im Ingenieurwesen u. Entw. + Bauen von komplexen Prod. u. können gut zB. Vergleich sophisticated Mercedes u. banaler Tesla → jedoch Tesla GM attraktiv! → soll heißen es geht nicht nur um technol. Lösungen!

→ Frage d. Herausforderungen ist für wen? Sowohl weltweit mit USA, Asien u. Europa als auch innerhalb der EU (GER/AUT vs. SPA → wir viel höhere Ind.quote)

→ Herausf. können technologisch sein, genauso wie regional oder sozial!

AUT: autom. + dig. in der Prod. stark gegriffen → Unt. + Gewerkschaften sagen alle d. gr. Arb.platzverlust was in den 80-90er Jahren → gr. Unt. die in Dig. investieren bauen Leute auf zB Magna gerade 3000 Leute

→ blue u. white collar workers: wenn ich Algorythmen habe brauch ich noch Leute?

→ hingegen werden verstärkt Leute wieder in Prod. eingesetzt (zB bei Tesla) da zu starke Autom. eine so hohe Komplexität hat das man damit nicht umgehen kann.

AUT: keine großen Personaleinbußen in Produktion

David Uecker
david.uecker@da-vienna.at
May 2018

TU WIEN CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

1.5 Where do you see Industry 4.0 at the moment? (e.g. concerning stage of implementation or which sector is a role model) / Wo sehen Sie Industrie 4.0 aktuell? (beispielsweise hinsichtlich Stadium der Implementierung oder welcher Sektor als Vorbild gilt)

→ Fokus von I4.0 auf prod. Sektor → schwer zu sagen dass ein Sektor vorne liegt, da es in den diversen Sektoren Unt. gibt die sehr weit sind u. andere die hinterher hinken.

→ tendenziell ein eher gut entw. Sektor ist automotive, weil diese seit langem zB. diverse Fahrzeugkonfiguratoren haben, was ~~[illegible]~~ eine sehr flexible Produktion gerade benötigt.

→ oft sind Zulieferer im automotive Sektor weiter als Hersteller selbst

(→ auch Medizintechniksparte)

→ allgemein für den deutschspr. Raum spricht ~~das Lehrlings-system~~ die Struktur der Lehrlingsausbildung, da dies zu hochqualifizierten MA führt und diese sich in einem unter I4.0 permanent verändernden Prod.prozess verhältnismäßig leicht zurecht finden.

zB. Liebherr mit Werken in Aut u. USA: können komplexe Prod. in USA nicht fertigen weil die MA diese nicht machen können/überfordert sind.

David Uecker
✉ david.uecker@da-vienna.at

May 2018

TU WIEN > CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

2. Questions with environmental focus
2.1 Do you see a nexus between industry 4.0 and the environment? If so, how does this connection look like? / Sehen Sie einen Zusammenhang zwischen Industrie 4.0 und der Umwelt? Falls ja, wie sieht dieser Ihrer Meinung nach aus?
pos. Beispiele aus Prod.: → u can only manage what u can measure → wenn ich weiß wieviel Energieverbrauch ist, kann ich erst etwas tun → ETH Studenten beispiel mit Wasserverbrauch → Visualisierung führt zu Verhaltensveränderung! → da bei jedem Prod.schritt Qualität gemessen wird, wird Ausschuß massiv reduziert. → Statistik: Mensch macht 500-600 Fehler pro 10.000 Tätigkeiten in der Arbeit → mit I4.0 ↓ auf 8-10/10.000 → ↓Fehler → ↓Ausschuß → Betrachtungsfokus nicht nur auf Prod.prozesse sondern das gesamte Gebäude z.B. wenn Fenster falsch angebracht sind und Sonne Wärme einfällt o. ein Sensor ausfällt od. ausgelöst wird → Digitaler Zwilling: verstärkt nicht nur virtuell entwickeln eines Prototypen bevor man es baut, sondern Prod. wird simuliert → erst wenn Prod. auf Simulator perfekt passt wird es in die Tat umgesetzt → massive Ressourceneinsparung → 3D Druck: gr. Potenzial für Materialeinsparungen, da es keinen Abfall gibt
2.2 Is there something like a "Sustainable Industry 4.0" concept? If so, what are its features? / Gibt es so etwas wie ein "nachhaltiges Industrie 4.0" Konzept? Falls ja, wie lauten die Charakteristika?
→ hat noch nie von einem Unt. gehört, das I4.0 einführt aus Nachhaltigkeitsgründen, → Auswirkungen auf Umwelt aus unternehmerischer Sicht sind kollateral Nutzen od. Schaden → Optimierung der Logistik um Stillstandszeiten zu minimieren geht in die selbe Richtung → just-in-time

David Uecker ✉ david.uecker@da-vienna.at
May 2018

TU WIEN CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

2.3 Research question: What are the most prominent positive as well as negative changes concerning the environment that Industry 4.0 entails? / Forschungsfrage: Was sind die prominentesten positiven sowie negativen Veränderungen, die Industrie 4.0 hinsichtlich der Umwelt mit sich bringt? - *alternative formulation: What are the positive as well as negative effects that Industry 4.0 can have on the environment? / Was sind die positive sowie negative Effekte die Industrie 4.0 auf die Umwelt haben kann?*

auch Datenerhebung/ -erfassung und -analyse

neg.: Blockchain Technologie → enormer Energiefresser!
höherer Energieverbrauch
auch pos. Aspekte → zB eine Pille kann wie Blockchain nachverfolgt werden, das diese vom Original Produzenten stammt und eben keine Fälschung.

pos.: Effizienzsteigerungen → zB bessere Auslastung der Anlagen
welche zu Schonung von Ressourcen führt
bessere Nutzung von Ressourcen → weniger Abfall, → Ausschuß,
durch weniger Energie → ~~[illegible]~~

→ eigentl. redu. von Energiebedarf da Effiz.steig. aber zusätzl. Techn. braucht En. u. somit möglich, dass En.bedarf allg. ansteigt! → um diesen zusätzl. En.bedarf andecken ist umfassende Infrastruktur benötigt → öffentl. Hand gefragt.
→ allgemein: holistischer Ansatz nötig → zB Smart Cities
aber ist unfassbar komplex!

insbesondere hinsichtl. bestehender Geräte: bessere Nutzung durch zB sharing economy bei Autos → weniger Autos werden verkauft, was für Automotive Branche schlecht ist, aber die verkauften werden besser genutzt → overall Emissions ↓ zu erwarten also positiv für Umwelt
→ auch Maschinen → brauchen weniger input für selben output.
↓ in raw materials

GM { → Digitalisierung an sich: zB Musik: früher CD, Schallplatte, etc. – heute digital
→ Strom ↑ aber Ressourcen ↓ und auch schneller!

David Uecker ✉ david.uecker@da-vienna.at
May 2018

TU WIEN CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

2.4 How much can be done regarding the environment with aspects such as increasing transparency, illustration of data (e.g. real-time emission data), etc.? / Wie viel kann mit Aspekten wie Transparenzsteigerung, Darstellung von Daten (zB Echtzeit-Emissionsdaten) hinsichtlich der Umwelt gemacht werden?

→ "Visualisierung führt zu Verhaltensänderung" → Transparenzsteigerung u. Darst. von Daten führt zu nachhaltigerem Verhalten (Bewusstseinsschaffung)

Projekt "Supermärkte" (in Irland): sehr unterschiedliche Energieverbräuche in den unt. Filialen → Tiefkühlgeräte waren auf unterschiedl. Temperaturen gestellt → bis zu 50 % mehr Energieverbrauch → als man gemessen hat (→ Transparenz in den Prozess brachte) hat man gesehen, dass großes Einsparungspotenzial besteht da man optimale Temp. eruierte (weil ich messe konnte ich es darstellen, sehen u. verändern.) → weiters: Kameras am Parkplatz, wenn viele Autos kommen wurde Temp. (↓) verändert weil man wusste die Tiefkühlgeräte werden jetzt häufiger geöffnet → Effizienzst. und damit Kosteneinsparung und Kosten ↓

2.5 Are changes in legislation required in order to be able to profit from potential benefits for the environment coming with the implementation of Industry 4.0 or will these benefits be inevitable? / Ist eine Änderung der Gesetzeslage notwendig um von den möglichen Vorteilen, die die Implementierung von Industrie 4.0 mit sich bringt zu profitieren oder sind diese unumgänglich?

Unt. sollten nicht durch Gesetze "genötigt" werden sondern eher mittels politischer Initiativen motiviert werden sich in Richtung I4.0 zu entwickeln → NÖ: bei größeren Bauprojekten die öffentl. ausgeschrieben werden, muss BIM angewendet werden → für größere wie PORR od. STRABAG kein Problem, und kl. lokale Baufirmen bekommen Schulungen

→ Devise: ~~[illegible]~~ Inzentivieren statt unter Druck setzen

neben Gesetzen benötigt es eine Reihe an Politikinstrumenten, die noch besser geeignet sind Handlungen zu verändern, zB. mittels Forschungsförderungsinstrumente Unt. motivieren mit Wissenschaftl. Einrichtungen zus. zu arbeiten

→ öffentliche Hand ist gefragt u. hat großes Pot. um hier etwas zu verändern

→ Staat kann auch mittels zB Regierungsprogramm ein Thema in den Fokus bringen → im neuen Reg.prog. kommt Begriff Digitalisierung 89x vor.

→ eher soft facts u. keine Gesetze gefragt!

David Uecker ✉ david.uecker@da-vienna.at
May 2018

TU WIEN CONTINUING EDUCATION CENTER

diplomatische akademie wien
Vienna School of International Studies
École des Hautes Études Internationales de Vienne

2.6 Do you know of an example where Industry 4.0 has been or currently is implemented in a "sustainable" manner? (consciously sustainable) / Wissen Sie ein Beispiel wo Industrie 4.0 bewusst nachhaltig implementiert wurde bzw. implementiert wird?

→ Eff. st. u. Res. schonung / bessere Nutzung bedeutet zu meist Kostenred. und das ist Hauptmotiv → Vorteile für Umwelt nimmt man gerne mit → kennt von keinem Beispiel das I 4.0 aus Nachhaltigkeitsgründen implementiert wurde
env. pillar

→ für sozial pillar jedoch schon → wichtig bei sustainability alle Ebenen zu berücksichtigen

~~→ Beispiel sozial:~~ hins. → sozial nachhaltig bietet I 4.0 tolle Möglichkeiten → zB Projekte bei denen Personen mit Behinderungen mit digitalen Assistenzsystemen ausstattet u. ihnen damit ermöglicht in einen Prod.prozess zu integrieren, sprich ihnen eine Job möglichkeit gibt

→ für private Wirt. gilt dass es kosteneffizient sein muss, nicht jedoch zwangsläufig für öffentl. Hand → deshalb auch wichtig eine Brücke dazw. zu haben, ~~[illegible]~~ sodass sich beide Seiten ~~[illegible]~~ kennen + verstehen.

3. Follow up comments and answers

→ kein Unt. wird viel in etwas investieren dass monetär nichts bringt nur um zu sagen das es grün ist.

Br. zw. Politik und pol. Prozessen u. priv. Wirtschaft u. Technologie zunehmend relevant!

David Uecker ✉ david.uecker@da-vienna.at

May 2018

Questionnaire for MSc Thesis

Industry 4.0 and its Effects on the Environment

Interview #A

Place, Date: Wien, 03.05.2018

Institution: Austrian Institute of Technology

Interview partner: DI Dr. Thomas Fleckl

Role: Head of Competence Unit Sustainable Thermal Energy Systems

1. General Questions
1.1 How would you define Industry 4.0? / Wie würden Sie Industrie 4.0 definieren? Voll vernetzte industrielle Produktion, die einen hohen Grad an Automatisierung, sowohl an den Prozessen als auf der Vernetzungsebene, aufweist und generiertes Wissen im System hält und darauf weiter aufbauen kann.
1.2 What is the role and aim of your institute? / Welche Rolle nimmt Ihr Institut ein und was ist Ihr Ziel? Das AIT ist ein angewandtes Forschungseinrichtung, dass für die Industrie oder gemeinsam mit der Industrie Lösungen und Technologien in unterschiedlichen Bereichen entwickelt. Im Bereich Industrie 4.0 zielen diese Entwicklungen u.a auf die Bereiche der "Digital Safety&Security", Energie, Mobilität, Visualisierung, Automatisierung/Regelung, Schnittstelle Mensch/Maschine, Entwicklung neuer Produktionstechnologien ab.

David Uecker ✉ david.uecker@da-vienna.at

1.3 What would you say are the most prominent benefits of Industry 4.0? / Was sind Ihrer Meinung nach die größten Potenziale von Industrie 4.0?

Industrie 4.0 muss auf jeden Fall einen Benefit für die Anwender im Vergleich zum State of the Art geben. Diese können sein,
Verbesserung von Qualität in der Produktion, Erhöhung von Energie- und Ressourceneffizienz, Reduktion von Kosten (u.a. in der Wartung)
Speicherung von Wissen und Expertenerfahrung in Modellen und daraus Generierung von neuem Wissen ("machine learning")
Automatisierung von wiederkehrenden Tätigkeiten
Erhöhung von Arbeitssicherheit
Kundenspezifische Produktion ("Losgröße 1"),
Einsatz neuer Produktionsverfahren (additive Verfahren, Nanotechnologien)

1.4 What would you say are the major challenges coming with Industry 4.0? / Was sind Ihrer Meinung nach die größten Herausforderungen, die Industrie 4.0 mit sich bringt?

Verstehen des Benefits und die Umsetzung. In vielen Bereichen ist der Mehrwert (noch) nicht klar

Bearbeitung und Bewertung von großen Datenmengen.
Herausfiltern der relevanten Informationen aus den Datenmengen/Mustererkennung.
Datenverfügbarkeit, Datensicherheit
Interpretation der Informationen und Koppeln mit Expertenwissen.
Verfügbarkeit von echtzeitfähigen Modellen zur Regelung und Vorhersage
Sicherheitsaspekte im Bereich Daten und Know-how
Änderungen in der Arbeitswelt, genügend qualifizierte Mitarbeiter zu haben.

1.5 Where do you see Industry 4.0 at the moment? (e.g. concerning stage of implementation or which sector is a role model) / Wo sehen Sie Industrie 4.0 aktuell? (beispielsweise hinsichtlich Stadium der Implementierung oder welcher Sektor als Vorbild gilt)

Durchdringung und Reifegrad ist sehr unterschiedlich. Vorbilder sicher sehr stark in der produzierenden Industrie (Stückgut). In der Bauindustrie sehr rudimentär vorhanden, wird aber immer mehr in der Branche als Notwendigkeit erkannt (umfassend im integrierten Planen, Bauen und Betreiben). In der thermischen Prozessindustrie sind die Stadien sehr unterschiedlich. In vielen Fällen muss der Mehrwert einer Vernetzung erst erkannt und nachgewiesen werden. Anlagen sind meisten auf eine effiziente Produktion ausgelegt und nicht unbedingt auf eine flexible Produktion.

2. Questions with environmental focus
2.1 Do you see a nexus between industry 4.0 and the environment? If so, how does this connection look like? / Sehen Sie einen Zusammenhang zwischen Industrie 4.0 und der Umwelt? Falls ja, wie sieht dieser Ihrer Meinung nach aus? Ein sehr starker Zusammenhang gibt es im Bereich der Energieeffizienz und des Einsatzes von fluktuierenden Erneuerbaren Energieträgern. Generell kann Industrie 4.0 zur Optimierung des Ressourceneinsatzes (Material, Energie, Abfälle, Emissionen) in der Produktion eingesetzt werden. Dieses kann aber auch im Konflikt mit Zielgrößen, wie z.B. Durchsatz, geringe Losgröße, flexible Produktion stehen.
2.2 Is there something like a "Sustainable Industry 4.0" concept? If so, what are its features? / Gibt es so etwas wie ein "nachhaltiges Industrie 4.0" Konzept? Falls ja, wie lauten die Charakteristika? Ist mir nicht bekannt. Nachhaltigkeit wird eher als Bestandsteil des 4.0 Konzeptes gesehen.

David Uecker ✉ david.uecker@da-vienna.at
May 2018

2.3 Research question: What are the most prominent positive as well as negative changes concerning the environment that Industry 4.0 entails? / Forschungsfrage: Was sind die prominentesten positiven sowie negativen Veränderungen, die Industrie 4.0 hinsichtlich der Umwelt mit sich bringt?

- *alternative formulation: What are the positive as well as negative effects that Industry 4.0 can have on the environment? / Was sind die positive sowie negative Effekte die Industrie 4.0 auf die Umwelt haben kann?*

Positiv:

Erkennen von Fehlern, Ausfällen etc. in der Produktion,==>Unterbrechungen kosten Zeit und Energie
Zielgerichtete Wartung
Bessere Ressourcennutzung möglich
Wissen und Erfahrung wird im System behalten
Maßgeschneiderte Fertigung, die lokaler erfolgen kann.

Negativ:
Produktion kann noch billiger werden, da weniger Personal gebraucht wird. Kapazitäten können erhöht werden. Daher kein direktes Ziel Produkte langlebiger und damit über den Lebenszyklus nachhaltiger zu machen.
Losgröße 1 ist wahrscheinlich in vielen Fällen ineffizienter, als eine Massenfertigung

2.4 How much can be done regarding the environment with aspects such as increasing transparency, illustration of data (e.g. real-time emission data), etc.? / Wie viel kann mit Aspekten wie Transparenzsteigerung, Darstellung von Daten (zB Echtzeit-Emissionsdaten) hinsichtlich der Umwelt gemacht werden?

Daten müssen auf jeden Fall auch mit einer Interpretation verknüpft werden (z.B. Überschreitungen von Emissionwerten beim Hochfahren einer Anlage), damit es zu keinen ungewollten Missverständnissen kommt. Echtzeitdaten könnten vermutlich in Richtung von überwachenden Behörden interessant sein. Generelle Daten eines Produktes (z.B. CO2 Abdruck, Herkunft, Ressourcenverbrauch) könnten für den Endkunden für die Kaufentscheidung von Interesse sein und somit für die Nachhaltigkeit von Vorteil sein.

2.5 Are changes in legislation required in order to be able to profit from potential benefits for the environment coming with the implementation of Industry 4.0 or will these benefits be inevitable? / Ist eine Änderung der Gesetzeslage notwendig um von den möglichen Vorteilen, die die Implementierung von Industrie 4.0 mit sich bringt zu profitieren oder sind diese unumgänglich?

Es ist wahrscheinlich unumgänglich, dass sich Gesetzeslagen ändern, da Industrie 4.0 fundamentale Änderungen in der Arbeitswelt, in den Produktionsabläufen, Schnittstellen Mensch-Maschine in der Produktion, Umweltauswirkungen, Steuereinnahmen für die Staaten etc. bewirkt.

2.6 Do you know of an example where Industry 4.0 has been or currently is implemented in a "sustainable" manner? (consciously sustainable) / Wissen Sie ein Beispiel wo Industrie 4.0 bewusst nachhaltig implementiert wurde bzw. implementiert wird?
Ist eher umgekehrt zu sehen, nämlich die Implementierung bewirkt eine Ressourcenschonung. Im erweiterten Sinn ist ein Beispiel der Implementierung eines direkten Stromhandels mittels Blockchain zwischen den Erzeugern (PV) und Verbrauchern (Einzelkonsumenten) in New York zu sehen.
3. Follow up comments and answers