Industry 4.0 and Circular Economy in Chemical Industry of the Czech Republic – First Mapping

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Abstract

Industry 4.0 and Circular Economy are two new concepts that change the form of the current industry. Industry 4.0 is a concept that involves modern technologies, such as the Internet of Things, Advanced Digitalization and Robotics, Big Data processing, etc. It has a potential to make corporate processes significantly more effective across the entire supply chain. Circular Economy is a concept focussing on circulation of material and energy flows in the current market environment. This concept has a potential to decrease the negative impacts of companies and their products on the environment. This paper represents a primary probe into chemical companies in the Czech Republic, and it aims to identify the awareness, the stage of implementation, and potential blending of these concepts based on a questionnaire survey. A part of the respondents knows the concepts, and some of them even use some elements of Industry 4.0 within activities connected with Circular Economy. On the other hand, the research confirmed that some of the respondents are not aware of these concepts or of their contents, even though they are using some elements of Industry 4.0 or Circular Economy.

Keywords: Industry 4.0; Circular Economy; Sustainable Development, Czech Republic

Introduction

Sustainable Development is a concept introduced in 1987. The United Nations report defines it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987). The United Nations adopted “The 2030 Agenda for Sustainable Development”. This agenda has 17 goals marked as “Sustainable Development Goals” (SDG) (United Nations, 2020). Circular Economy (CE) has a significant potential to help fulfil the concept of permanently sustainable development (Dantas et al., 2020; Kristoffersen et al., 2020). CE is closely connected with SDG 12. It can also have positive impacts of SDG 6 and SDG 15 (Kristoffersen et al., 2020). CE is to support decarbonization and zero net greenhouse emissions before 2050 (Sachs et al., 2019).

One of SDGs is aiming at extension of digital infrastructure and technologies, which should also support circulation (Sachs et al., 2019). Technologies that could significantly contribute to effective circulation of flows include Industry 4.0 technologies (Dantas et al., 2020; Sachs et al., 2019).

The paper aims to find out whether Czech chemical companies apply CE and Industry 4.0 tools, whether they have already started implementing one or the other concept (or both), and whether they perceive mutual support and interconnection of these concepts.

Literature Review

Circular Economy

CE is not a new concept. It has always been here in different forms. However, the technological progress in the last century gave origin to the current and dominant business model called Linear Economy. Linear Economy functions on the principle of “take, make, distribute, consume, and dispose”. By contrast, CE aims to change the current model to “take

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biological and technical materials, make, distribute, consume, return biological and technical materials" (Dantas et al., 2020; De Angelis, 2018; Stahel, 2019). Linear Economy is in direct contradiction with CE, as it uses the principle of Planned Obsolescence, which supports continuous consumption (Alonso-Almeida et al., 2020; Kopnina, 2018). McDonough and Braungart (2002) introduced the concept of Cradle to Cradle, which popularized CE and is based on Industrial Ecology or on natural ecosystems and their cycles, which have inspired some business models. Mavropoulos & Nilsen (2018) offer a list of other directions, which can be at least partly considered as circular – apart from those already mentioned: Blue Economy, Biomimicry, Performance Economy, Natural Capitalism, Regenerative Design, Industrial Ecology, and Industrial Symbiosis, which is also mentioned by Stahel (2019) who adds the concepts of Circular Molecules and Bioeconomy, which share some principles with CE.

The main idea of CE is the fact that waste from one (finished) product life cycle represents a raw material for a new product (Awan, Sroufe, Shahbaz, 2021; Kopnina, 2018; Mavropoulos & Nilsen, 2020). To fulfil the CE concept, it is necessary to maintain the economic value and usability of products as long as possible and in the highest possible quality (Awan, Sroufe, Shahbaz, 2021; Stahel, 2019). This means that products have to be break-resistant and easily repairable – ideally, they should be infinitely reusable (Alonso-Almeida et al., 2020; Kopnina, 2018). Stahel (2019) states that the other elements that have to be taken into consideration when implementing Circular Business Models are as follows: infrastructure, buildings, vehicles, and production equipment all of which have to keep the highest possible value and endure as long as possible. The key factor is production materials, which literature divides into biological and technical (Dantas et al., 2020; De Angelis, 2018; Kumar et al., 2021). Biological, or renewable, materials should be designated without toxic components, which makes it possible to return them to nature after they have been exploited. However, even biological materials should primarily be reused in some other manufacturing processes that do not place high demands on the quality of biological inputs. The other type of materials is technical materials (synthetic or mineral). These should be kept in the manufacturing process through maintenance, repairs, renovations, reconditioning and recycling; and only under the condition that their quality is continuously maintained at the maximum possible level. These methods are mentioned in order of their effectiveness, i.e., recycling is, as the least effective method, the last option approached by CE, as the other methods better maintain the work and energy put into the product production process, and in addition, the energy must also come from renewable energy sources (De Angelis, 2018). Recycling is, within CE, perceived as Downcycling – i.e., a part of valuable material is lost forever with each following cycle (Kopnina, 2018).

Literature also mentions some important obstacles. Replacement of the linear economy by the CE does not have to be always suitable. It is also necessary to take account of energy demands placed on application of the CE principle or on the obstacles in recycling (Mavropoulos & Nilsen, 2020). Furthermore, each supply chain produces some waste in most operations. Waste does not comprise only products whose life cycles have ended. Waste is generated as early as during acquiring raw materials, during transport activities, but also during the final process of product recycling, i.e., turning it into raw materials. These wastes prevent 100% fulfilment of CE, and they are also the reason for the replenishment of manufacturing processes with new unrecycled resources (De Angelis, 2018; Mavropoulos & Nilsen, 2020). Lacy, Long and Spindler (2020) mention another obstacle in implementation of CE, which is a lack of financial capital. This is also confirmed by Dev, Shankar and Qaiser (2020). Another large barrier to implementation of CE on the part of customers is the fact that they are not sufficiently aware of the CE principles, or CE itself (Alonso-Almeida et al., 2020). There is a significant effect that appeared in the previous models that increased productivity. It is the so-called Rebound Effect. Basically, it is the effect of action and reaction, where increased efficiency and production results in increased consumption (Mavropoulos & Nilsen, 2020).

Implementation of CE will require changes in four areas: the product area, the company area, the supply chain areas, and the area of legislation (Stahel, 2016). CE also requires changes in the behaviour of customers, who are, within this context, expected i.e., to return the product or its packaging to a place for recycling after the end of their life cycle. Such a customer is described as "a working consumer" (Alonso-Almeida et al., 2020). Stahel (2019) adds that a customer in CE must focus on the product function and performance, which should represent the majority of the value, rather than fashion trends.

The potential advantages of implementation of the CE principles are of the environmental, economic, and social character:

Specifically, it is waste or greenhouse gas emission reduction. The environment will prosper not only thanks to a decrease in toxic emissions, but also thanks to vacation of some space by reducing landfill waste (De Angelis, 2018). Kumar et al. (2021) add that another emission reduction can be achieved e.g., through: SO2, NO, effluent and solid wastes and they agree with previously stated hazardous and toxic materials.

Another advantage is that waste from one process becomes an input into another. Therefore, the value of waste rises, and for the company, it is no longer a burden, but an opportunity. Moreover, the company can avoid the cost of waste disposal (Stahel, 2016). This also results in significant capital savings thanks to the saved materials and in the origination of new types of income. CE utilizes renewable energy resources only. Thanks to this, it is resistant to the external volatility of crude oil and other non-renewable resource prices. Companies will benefit from more stable input prices, cooperation with customers, and from new income from activities connected with CE created across the supply chain (De Angelis, 2018).

Application of the CE principles should lead to the creation of jobs and unemployment reduction in the areas connected with the key CE activities (machinery maintenance, recycling, etc.) (De Angelis, 2018). End customers should save some money thanks to the principles of sharing, where they prefer renting an expensive product, rather than buying. Another possible saving is based on a longer life cycle of purchased products (De Angelis, 2018).

CE also counts with application in the chemical industry, which is specific with its product diversity. The chemical industry is the largest consumer of industrial energy. The other problems include contaminated transport units, chemical waste dumps, manufacturing residues, etc. What is another huge problem is non-recycled polymers, which are largely contained in products or packages. CE mainly acquires traction thanks to the pressure the society places on the elimination of toxic waste created by by-products, but also by main products that might be harmful to the environment. The interest in CE is also caused by the gradual exploitation of natural sources. One of the great CE topics in chemistry is the consumption of the basic non-renewable raw materials used for production or as a source of energy. (Lacy, Long, Spindler, 2020).

Circular economy and Industry 4.0

One of the important enablers for CE is the Fourth Industrial Revolution (Sachs et al., 2019). The Fourth Industrial Revolution, also known as Industry 4.0, is currently in progress. The main driving force is cyber-physical production systems, working with both the physical and virtual worlds thanks to digitization (Mavropoulos & Nilsen, 2020). New technologies constituting the concept of Industry 4.0 are called Key Enabling Technologies (KET) (Yáñez, 2017). These technologies will make it possible to build systems that will be automated, that will analyse themselves, and that will be highly integrated (Dantas et al., 2020; Sukhodolov, 2019). Technologies constituting the concept of Industry 4.0 include, for example: Cyber-physical Systems, Internet of Things, Big Data, Additive Manufacturing, and Internet of Services, Cloud Computing, Virtual and Augmented Reality and Autonomous Robots or Vehicles (Awan, Sroufe, Shahbaz, 2021; Dantas et. al., 2020; Dev, Shankar, Qaiser, 2020). The technologies which make up the concept of Industry 4.0 have great potential to raise productivity, lower production costs, reduce emissions and reduce resource consumption (Dantas et. al., 2020; Sachs et al., 2019) and reduce impact on the environment (Awan, Sroufe, Shahbaz, 2021). It is no longer enough to innovate waste disposal. It is also necessary to innovate the areas of manufacturing, product design, and business models, and it is also necessary to take a new approach to consumption by the end customer (Mavropoulos & Nilsen, 2020).

New technologies create opportunities in utilization and "consumption" of resources and products (De Angelis, 2018). Industry 4.0 will enable flexible production that will save the basic inputs (which is, at the same time, a CE principle, as stated in the previous chapters). They include energy, raw materials, and human labour. Industry 4.0 will enable better utilization of data acquired from processes for their optimization. Information acquired from manufacturing processes will also enable optimized maintenance, which will be conducted based on actual wear and tear of e.g. production machines, which will save the production capital and prolong its life, also in the spirit of the CE concept (Mavropoulos & Nilsen, 2020). Dantas et al. (2020) state that application of the concept of Industry 4.0 will help minimize extraction of new raw materials and maximize utilization of already applied resources.

Literature identifies some opportunities for companies within CE. The first one is to develop technologies for the circulation of molecules e.g. through renewable bio-based raw materials, recycling (e.g. in PET bottles), or reusing (where polymers are divided into shorter ones and reused in different processes). Another opportunity can be found in digitization of successive "downstream" industries, which brings creation of new opportunities and savings (Lacy, Long, Spindler, 2020). Digital technologies of the Internet of Things can enable automatic monitoring of a place and condition of production resources. Big Data Technologies could help monitor inputs and outputs in the processes of Industrial Symbiosis in real time. Digital technologies are critical for monitoring material flows (raw materials, materials, but also products, etc.) (Kristoffersen et al., 2020). B2C and B2B supply chains must be interconnected (Stahel, 2016). Data acquired from these chains should help in decision-making processes in all product life cycle stages. Digital technologies for the application of CE models are not currently very advanced, even though they offer great potential (Kristoffersen et al., 2020). Data on environmental savings resulting from the application of the CE principles are insufficient and their shortage is a prove of "the lack of interest on the part of the mainstream economic research". If the data are available, the given production system benefits from them. (Stahel, 2019). Thanks to extensive data collection from all processes across the entire supply chain and product life cycles, it will be possible to monitor the current condition of products or their parts. This will help optimize their utilization and make it possible to monitor their condition even after the end of their use, which will be helpful in the next stage of the product life cycle (Mavropoulos & Nilsen, 2020).

Methodology

The method of a questionnaire survey was chosen for the qualitative research. The basic set included manufacturing companies, members of the Association of the Chemical Industry of the Czech Republic. 67 companies were addressed, and 8 of them sent back completed questionnaires. The questionnaire was sent to the competent persons of the respected companies in April 2021. The questioning ended in May 2021. Although this set cannot be described as a representative one, it brings an interesting insight into the corporate practice with respect to the assessed topis. The respondents were anonymized.

The questionnaire was created based on a literature review. The first part of the questionnaire was dedicated to general questions about the state of implementation of Industry 4.0 elements, and then it also focussed on the reasons for which the company approached this implementation. The next part of the questionnaire dealt with questions concerning CE. The respondents were asked whether they are aware of the term and then whether their companies apply the CE principles. Then they were asked about some particular CE concept methods, and finally whether they also use any elements of the Industry 4.0 concept for implementation of the CE elements. The last part of the questionnaire served for identification of the respondent.

In view of the number of respondents, the completed questionnaires were assessed on an individual basis, and the outcomes were summarized in an overview of the status identified at the researched companies broken down into partial outcomes from separate questions.

Results

There were 8 respondents from 8 chemical companies. Respondents are marked by letters as the research was anonymous. One company has 1-49 employees, five have 50-249 employees and one has more than 250 employees. Some companies date the length of their operation a long time ago as their predecessors were nationalised by the communist regime and later privatised. One company dates its history almost 150 years ago. However, all of the companies are operating for longer than 15 years.

Table 1. Characteristics of the respondents

Respondent	Number of employees	Legal Form	Respondent job position
A	250 or more	Llc.*	Head of the investment department
B	50-249	Plc.**	Head of Production
C	50-249	Llc.	Project engineer
D	50-249	Plc.	Production Manager
E	50-249	Llc.	Development worker
F	50-249	Plc.	Business Manager
G	50-249	Llc.	Modernization manager
H	1-49	Llc.	Operations manager

** Llc: Limited liability company*
*** Plc. Public limited company*

Summary of the knowledge of Industry 4.0 and application of its elements in practice

Although only three respondents answered the question of whether their management know the term Industry 4.0 or the Fourth Industrial Revolution yes, and five of them no, each respondent later on revealed, that they know some elements of this concept, and some companies even stated that they have introduced some of these elements at the company.

The question focussing on particular Industry 4.0 technologies discovered that the companies are aware of most terms. The answers are summarized in Table 1. The companies are not very aware of the term of Cyber-Physical Systems. Half of the companies know the terms of a Digital Twin and Extended Reality, and the majority of the respondents know the terms of the rest of the technologies – all the respondents are aware of digitalization.

Table 2. The companies' awareness of separate technologies

Technologies	# of respondents who have awareness about the technology
Digitalization	8
Robotization	7
3D Printing	7
Internet of Things	6
Cloud Computing	6
Artificial Intelligence	5
Big Data and advanced Business Intelligence	5
Augmented Reality	4
Digital Twin	4
Cyber-Physical Systems	2

The companies were then asked about the implemented Industry 4.0 elements. Table 2 summarizes the answers. In total, there are fewer positive answers (30) than negative ones (58). This implies that the companies have introduced some key technologies, but more of them are not being used. The most widely implemented element is Digitization, followed by Cloud Computing and Robotization.

Table 3. Implemented KET in companies

Technologies	# of companies that implemented the technology
Digitalization	7
Cloud Computing	5
Robotization	5
Big Data and advanced Business Intelligence	4
Internet of Things	2
Digital Twin	2
Cyber-Physical Systems	1
Artificial Intelligence	1
3D Printing	1
Virtual Reality	1
Augmented Reality	1

Summary of CE and its support with the concept of Industry 4.0

The companies were subsequently inquired about the topic of CE. Half of the companies are aware of this term. Three companies stated that they are using the CE principle in their activities. The companies were asked in which areas of their activity they implement CE (Table 3, column 1). Then, whether they implement recycling or reuse, which are the most common CE activities. The companies mostly answered that they are using the CE principles in the area of manufacturing (2). However, the question about using any form of recycling or reuse was answered positively more frequently. Only one company stated that they are using an Industry 4.0 together with activities relating to CE. The CE principles are least used by the companies in the areas of services and administration. They are primarily manufacturing companies, so it is possible to assume that services do not belong to their main activity, which could have caused such contradictory answers.

Table 1. Summary of the status of CE implementation and utilization of its principles; and whether implementation is supported with Industry 4.0

Areas	We apply a CE principle	We apply a method of recycling or reuse	For this purpose, we use Industry 4.0 elements	None of the mentioned
Product manufacturing	2	5	0	1
Provision of services	0	2	0	6
Logistics/transport	0	3	1	4
Power engineering	1	3	0	4
Maintenance	1	3	0	4
Administration	0	2	0	6
Investments in corporate infrastructure	1	3	0	4

A form of recycling or reuse has been used by at least one company in each of the offered areas. Mostly in the area of product manufacturing and in logistics and maintenance (see Table 3). On the other hand, services and power engineering are areas where these CE methods are applied least (see Table 3). The thing is that the addressed companies are manufacturers, where services do not belong to the main activity. Only one company stated that they also use Industry 4.0 together with the CE activities in the area of logistics and transport. These answers also confirmed the lack of awareness of the contents of the basic terms, where the companies declared utilization of reuse and recycling in all the areas, but utilization of CE in four only.

The complementary information acquired from the questionnaire showed that one company has already introduced the CE concept in the form of environmentally friendly manufacturing of their products, and they are also using the CE principles in logistics at the same time. It is also the only company applying the Industry 4.0 tools in logistics to fulfil the CE concept. Another company also takes account of the CE concept within investments in the corporate infrastructure.

Discussion

The companies declared that they are not aware of the terms of Industry 4.0 or CE, but later they stated that they are implementing their elements. Therefore, this implies that both terms are still not generally known, but some of their elements are. It is slightly surprising that the term “Cyber-physical Systems” is still quite unknown as it is the cornerstone of Industry 4.0.

Two companies stated that they are using a modern Industry 4.0 technology also contributing to the mitigation of the environmental impacts of the corporate activity. As an example, the respondent mentioned the use of waste for biogas production, and another respondent – introduction of more environmentally friendly manufacturing of their products. The use of waste for biogas production fulfils the CE concept, and the company uses Industry 4.0 for this activity at the same time. And this is tangible evidence of the fact that these two concepts do not exclude each other and that Industry 4.0 elements can be used for implementation of CE.

The companies stated that most of them apply recycling or reusing in some of their activities, but they do not connect these activities with CE, even though they are its parts. Therefore, there is a contradiction. This contradiction is used below for a new research proposal.

The research outcomes did not confirm that Czech chemical companies actively use Industry 4.0 elements in a large extent to support CE, which disconfirms the theoretical grounds in the Literature Review, which mentions a high potential of mutual support. The statement that digital technologies are not sufficiently used for application of CE models at the moment has been confirmed.

There is plenty of research of the topics of Industry 4.0 and Circular Economy however research connecting these two topics is only just beginning to emerge mostly in form of literature reviews (such as: Rajput, Singh, 2019), barrier analysis (such as: Abdul-Hamid et. Al., 2020) or business model proposals (such as: Nascimento et. al. 2019). Yu, Khan, and Umar (2021) published a study about usage of the two concepts in practice however respondents were from automobile industry.

This study did not explore awareness of managers about the concepts. Results did not state how many respondents were not aware of these concepts at all. The novelty of our research lies in connection of these two concepts with chemical industry and furthermore it focuses on awareness about these concepts in the companies of chemical industry.

The outcomes of this research are a good basis for quantitative research, which could identify how much chemical companies are aware of the concepts of Industry 4.0 and CE, and into what extent they are applied. Although the terms have been scientifically described and these two terms are used in the academic sphere, the practice shows the opposite. Companies implement Industry 4.0 elements and apply methods relating to CE without connecting them with these concepts. The research would also be of a certain value even if it was conducted in different regions or in different industries for comparison. For example: comparison of Czech chemical companies with the neighbouring countries or EU countries. Research about Industry 4.0 terminology and implementation in Czechia is currently in the progress.

The research was focussed on the initial identification of utilization of Industry 4.0 and CE elements in the chemical industry, and it has created a basis for another potential research, which would analyse the situation in companies in more detail. It would be of benefit if it assessed selected Industry 4.0 elements or technologies and how the elements help fulfil not only the CE concept, but also e.g., the concept of Sustainable Development, or its SDGs.

Although the professional literature deals with the combination of CE and Industry 4.0, there is no research focussing on the chemical industry, which has its specifics. It would be useful to identify which Industry 4.0 technologies have the highest potential to support effective implementation of CE in chemical companies.

The method of a questionnaire survey proved to be the right choice with respect to the pandemic situation. Thanks to the electronic form of questioning, the response rate was, for the purpose of the qualitative research, relatively high. On the other hand, there is still a lot of space for detailed assessment of individual Industry 4.0 elements and their specific application within CE. This research laid the foundation for future quantitative research, and it has shown the barriers (mostly in form of unclear terminology) that need to be overcome before this research can be conducted.

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