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The Journal of Business Chemistry (JoBC) focusses on current developments and insights at the intersection of management and chemistry, biotechnology or pharmacy.
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Letter from the Editors

The ecosystem perspective

Research around how to organize activities inside and outside of firm boundaries is well established in strategy and innovation management literature. As new customer needs evolve, companies can no longer rely solely on their own capabilities but instead on partners within the framework of ecosystems. Ecosystems are composed of interconnected and interdependent network actors, which simultaneously create a value proposition for the customer by combining complementary skills and assets. Similarly, individual companies benefit from the ecosystem by developing superior products and services which outperform their competitors or by entering new markets. Through their partners, companies gain access to customers, competencies and resources which they usually don't possess and therefore need to build up by themselves at high costs. Due to the complex character of value chains in the chemical industry, an active engagement in ecosystems provide ample opportunities for chemical companies to growth and to gain competitive advantages. In order to enrich the 'knowledge ecosystem' of our readers the Journal of Business Chemistry is proud to present the following articles.

In spotlight "Lessons from "Goodbye Hoechst"" Hermann Simon shares his opinion on why the former Hoechst AG failed. His contribution is a reply to the book "Goodbye Hoechst" by Karl-Heinz Seifert and covers lessons learned from the company's decline which are still highly relevant today.

In their commentary "The Digital Revolution is coming to chemical laboratories" Michael Ulbrich and Vikas Aggarwal describe how chemical companies can harness the potential of digital R&D. While digital R&D is already state-of-the-art in industries such as healthcare and life-science, chemical companies can increase their organizational and innovation performance by transforming R&D operations into a "Laboratory 4.0".

The article "The relation of energy value chains, global GDP and CO2 taxes" by Andreas Otterbach illustrates how the global energy consumption is linked to economic activity, CO2 generation and well-being. The author opts for a significant increase of renewable energy and transparency in CO2 consumption.

The first contribution in our Practitioner's Section comes from Thorsten Bergmann, Carola Guyot-Phung and Delphine Antoniucci. Their article "How digital tools make circular economy operational in industrial areas: The example of BE CIRCLE" deals with the outcomes and learnings of three case studies where the digital tool BE CIRCLE has been used to optimize resource flows and close loops.

Steffen Wasmus and Marius Chofor Asaba explore critical success factors for improving the sustainability of communication devices. Moreover, their article "Challenges and opportunities in the sustainability of communication devices - an operator perspectives exemplified by Deutsche Telekom AG" provides circular economy implementation strategies for communication devices.

In his article "The smart-up ecosystem: Turning Open Innovation into smart business", Maarten van Gils introduces the smart-up ecosystem concept, which supports SMEs for the smart industry transformation. The article summarizes the author's multiple project experience and provides insights from the Dutch chemical industry.

The Research Paper "Managing product variety under operational constraints: A process-industrial outlook" by Peter Samuelson and Thomas Lager introduces a conceptual framework on "platform-based design of non-assembled products". The authors empirically test it in the Nordic process industries and their findings acknowledge the applicability of many components of the framework.

Now, please enjoy reading the second issue of the sixteenth volume of the Journal of Business Chemistry. We are grateful for the support of all authors and reviewers for this new issue. If you have any comments or suggestions, please do not hesitate to contact us at contact@businesschemistry.org.

Thomas Kopel Bernd Winters

(Executive Editor) (Executive Editor)

Journal of Business Chemistry

Spotlight

Lessons from "Goodbye Hoechst"

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The disappearance of the German Hoechst Corporation, is even 30 years after the start of the restructuring still a topic of high interest to managers in the chemical and pharmaceutical industries. Over the years, a variety of publications have described, analyzed and evaluated the restructuring process that has finally lead to the disappearance of the company.

In 2018, Karl-Heinz Seifert has published a book in German language with the title "Goodbye Hoechst". It is no ordinary book about the decline of a former pearl of the German economy. The author is one of the "experts, players and charlatans" from the subtitle. From 1988 to 1997 he was a board member of Hoechst. Seifert provides a meticulous record of the decline, backed up by numerous internal documents. For me, the book read like a detective story and I felt personally touched. My emotional involvement stems from the fact that I accompanied Hoechst for more than two decades as a consultant, top management trainer and speaker at their management conferences. I know many of the managers mentioned in the book personally.

Founded under the name of Meister, Lucius & Co. in Frankfurt Höchst in 1963, the company grew over the years into one of the largest chemical and pharmaceutical companies in the world. Hoechst occupied top positions in the world market until the 1990s. In 1990, Hoechst achieved a revenue of 45 billion DM, similar to BASF's 47 billion DM and Bayer's 42 billion DM.

In 1994, Jürgen Dormann became CEO, and initiated a major reorganization of the highly complex company. The portfolio was diversified with activities in chemicals (accounting for 27 percent of sales), health (24 percent of sales), fibers (15 percent), polymers (14%), engineering and technology (12%), and agriculture (8%). The company was very international with three quarters of the sales being generated abroad, and research oriented with R&D centers in 17 countries and dedicating a higher percentage of its budget to R&D than competitors. At the same time, profit was below the industry standard.

Seifert names Jürgen Dormann as the main culprit for the demise of Hoechst. Dormann initially headed the influential central management department, a kind of internal strategic think tank. From there he was appointed to the board in 1984, without any operational or international experience. From 1994 to 2003 he served as Chief Executive Office of Hoechst and Aventis, respectively, into which the rest of Hoechst merged. I have to admit that, as a member of the jury, I was co-responsible for Dormann's election to "Manager of the Year 1995" and in 1996, in a speech to Hoechst executives, I praised his America strategy.

I do not deny Seifert's analysis as such. However, I see Seifert's role more critically than he does. While reading the book I repeatedly asked myself why Seifert did not intervene more effectively although he recognized mistakes early on.

Seifert sees Dormann's shareholder value orientation as the root of the disaster. I do not share this view. What Dormann executed was the opposite of shareholder value. Seifert also wrangles with valuations and represses the fact that the stock market value ultimately counts in mergers and acquisitions. In capitalism, value is what the market pays, not what a chemist or an engineer thinks it is.

The lessons which can be learned from the Hoechst case remain highly relevant until today – not only, but especially for the chemical industry. What are these lessons?

1 Avoid over-complexity:

I see the root of Hoechst's demise – different from Seifert - much earlier in an unmanageable over-complexity. This complexity already originate in the split up IG Farben, the German "supercorporation" after the Second World War. Hoechst received a far more diversified portfolio and many more locations than BASF and Bayer. This complexity was further increased through acquisitions and joint ventures under Hoechst's first CEO, the legendary Karl Winnacker, and his successor Rolf Sammet. When I first got to closely know Hoechst in the mid-1970s, the company comprised some 400 companies with a myriad of sites. There may have been some justification for the product portfolio from a purely chemical perspective. The portfolio ranged from pharmaceuticals, where Hoechst was the global number one until the mid '80s, to fibers, paints, cosmetics, photocopiers, agrochemicals, production plants and many other activities. While there may have been chemical commonalities, the markets served were completely disjointed, a problem that some former Hoechst-managers still do not understand until today.

In addition, in some of the subsidiaries Hoechst did not have a real grip. The most prominent example was the French subsidiary Roussel-Uclaf. In spite of owning 76 percent Hoechst could never implement a consistent strategy. The same was more or less true for some 50:50 joint ventures. Hoechst was a deterrent example of over-complexity. The general lesson: Companies should beware of excessive diversification. Managers should not give in to the illusion of being able to control everything. Hoechst paid too little attention to this doctrine. Siemens and Bayer proved to be wiser in this respect. They spun off many businesses when it was still early enough.

2 Highest requirements for top positions:

Seifert provides countless proofs of weaknesses that have crept into management over the years - primarily at the board level, and less so in the management of the business divisions. According to former Hoechst-managers, this misguided development can be traced back to Winnacker, who preferred yesman rather than strong people under himself. One can only be surprised at some of the behaviors. After a major chemical accident at the Griesheim plant in 1993, CEO Wolfgang Hilger only returned from his winter vacation after ten days. I don't have any understanding for such behavior. I expect total commitment from a CEO in major emergency situations.

3 Improve international competencies:

In intense negotations Hoechst's managers were no match for the Americans, the French and later also the Swiss. This is not a Hoechst-specific problem. In the Mannesmann-Vodafone merger 20 years ago the relative powers revealed a similar pattern. Where does this weakness of the Germans come from? Does the Nazi trauma still show its effects? Is the lack of command of the English language a problem? French managers mercilessly play off their political relations. Anyone who studied at Harvard, Oxford or the ENA has a network that German managers generally lack.

4 Take stock market valuations seriously:

The low valuation of German companies is still a sword of Damocles today. This has not changed fundamentally since Hoechst's times. In 2018 Bayer paid 66 billion US-dollars for Monsanto, in February 2019 the market capitalization of Bayer (including Monsanto!) is 63 billion US-dollars (56 billion Euros). How can that be? However, an easy solution for this problem is not in sight. But whether the Germans like it or not, ultimately the market value counts.

5 The board must control, not nod off:

The role of the supervisory board and the German worker-codetermination was detrimental to Hoechst. How can it be that the supervisory board didn't stop Dormann? Erhard Bouillon, whom I personally hold in great esteem, became Chairman of the Supervisory Board after many years as Chief Human Resources Officer. He was not up to the tasks. Even the worker representatives on the supervisory board endorsed Dormann's actions, certainly not a glorious sign of German codetermination.

All these lessons remain highly relevant. We should be grateful to Seifert for presenting this enormous case study on Hoechst's decline. It at least has a positive side. Companies and managers, not only in Germany, can and should learn from the mistakes made.

Commentary

The Digital Revolution is coming to chemical laboratories

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1 Introduction

When discussing the potential of digital technologies in research and development (R&D), people typically draw the line at so-called creative tasks. They see a clear division of labor, where creativity is the domain of humans and more mundane tasks are handled by machines. But that assumption comes into question when one considers both the current state of digital technologies and the nature of creativity itself.

Creativity is essentially the ability to develop or generate something novel. It can be something intangible like a magazine article, something physical like a new tool, or something artistic like a painting. But those things are usually the end result of a fairly long chain of events- the outcomes of a creative process. That is especially true when it comes to R&D. When a new material, for example, enters the development phase, that step has typically been preceded by years of research, trial-and-error testing and experience that inform development. In most cases, that creative development step is a logical continuation of historic findings, rather than a flash of insight from out of the blue. R&D creativity, like genius, is usually "1 percent inspiration and 99 percent perspiration", as the saying goes.

That hard "pre-work" is exactly where digital technologies are strong- and in many cases much stronger than humans. For example, machines (Microsoft Corporation, 2018):

- Are capable of accessing huge amounts of data within seconds, and are therefore fast when it comes to handling data.
- Have a near-unlimited storage capacity, and thus never "forget."
- Analyze data without prejudice and bias, and thus can draw objective conclusions based on probability and hard data.

With these capabilities, technology can be highly useful in many parts of the creative R&D process. And now, artificial intelligence (AI) is enhancing technology's capabilities even further, and making it suitable for tasks previously considered impossible for machines, such as predicting global market development and customer behaviors- or the behavior of new materials. As a consequence, digital and AI-enabled R&D is already state-of-the-art in industries such as life-sciences and healthcare, where it has proven to be especially useful in activities such as analyzing pharmaceutical activity profiles or identifying targets for personalized therapy within human DNA.

The chemical industry, however, has been slower to embrace this technology revolution in the lab. Often, researchers and developers in chemical laboratories are still engaged in manual, routine work, setting up experiments and monitoring or evaluating results with only rudimentary software support. They operate in disconnected information-technology islands, as well. Even if data is stored in an electronic laboratory note book (ELN) rather than on paper, a lack of technology integration between the business units and problems with validating data mean that many employees in the organization will struggle to quickly access that information. But evolving technology is now creating new opportunities for chemical companies to address those problems- and transform R&D to make it more efficient and effective in helping the company compete.

2 A new era of digitalization and automation

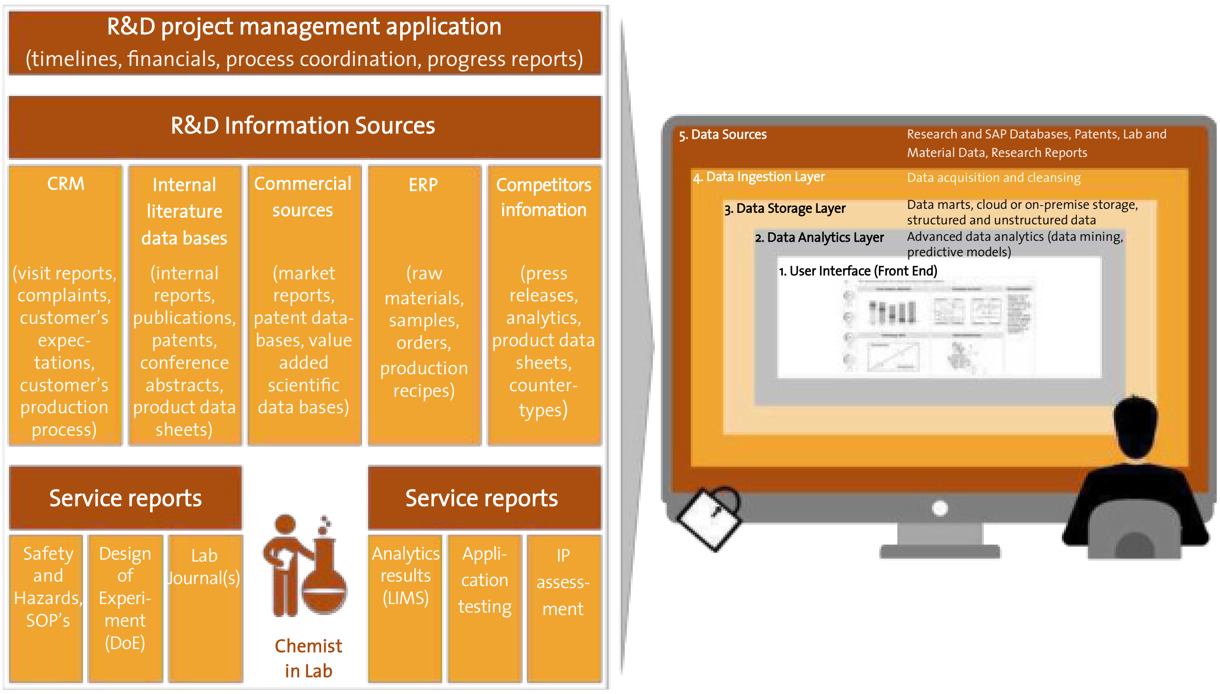
Why have chemical companies not embraced digital R&D, while other similar industries have? The answer lies in the nature of the data chemical companies work with, and their traditional approach to testing. For example, in the pharmaceutical industry, regulations essentially require drugs to be tested using defined protocols on large sets of subjects, with the effects being closely monitored over time-sometimes for years. This process produces a comprehensive set of data around the substance being tested.

In contrast, innovation in the chemical industry is usually focused on various, highly customized products for specific applications. After successful testing within the R&D lab, the innovation process gradually shifts via pilot plant to technical service departments. There, the product is fine-tuned to specific customer production lines through a few trial-and-error iterations. With the new product complete, the process is essentially repeated for the next product and customer. With this approach, data is generated at different points along the internal and external value chain, and various customized products are run through the process separately. Thus, the data is usually scattered among many stakeholders, and is typically not kept in a standardized format. Historically, dealing with this disparate data has been more than rules-based software can handle. However, that has changed, with technologies such as big data analytics, AI, data-lake architectures and lab automation making it possible to leverage that disparate data to accelerate R&D.

Through the targeted use of technology, R&D departments in the chemical industry can achieve greater efficiency and contribute significantly to competitive advantage. Potential benefits include a reduction of up to 5 percent in lead time from idea generation to market launch of new products; a 5 percent to 10 percent increase in R&D throughput in the form of new commercial products; a portfolio shift to higher value products; and a 25 percent to 35 percent increase in employee efficiency (Accenture, 2018).

Looking further, the technology can enable greater benefits over time as it transforms

Figure 1 Legacy IT systems a lab researcher has to deal with, contrasted with a fully data-integrated Laboratory 4.0 layered architecture (source: own representation).



R&D. Chemical companies can create “Laboratory 4.0” operations by weaving lab technologies into a cohesive whole, with data from various pieces of lab equipment being automatically captured and routed to where it is needed- helping to both reduce costs and enhance creativity (see Figure 1).

3 Productivity boost through AI and simulations

Today, so-called strong AI, an intelligence indistinguishable from human intelligence, is yet to be realized. But so-called weak AI, which focuses on performing specific tasks, is here and having a clear impact. Indeed, AI is opening the door to a quantum leap in innovation and productivity. Using historic and current data, AI -capable supercomputers can now identify hidden relationships between molecular structure or formulation composition and the observed overall performance of a material. This makes it possible to quickly find new structure-effect relationships- potential innovations- that probably would not be discovered without the use of AI. Over time, machine learning, a type of AI, can create a database of such relationships, which can be used to develop new, currently unknown products, or to precisely reverse-engineer already-formulated products. This may sound futuristic, but in some areas it is now a reality. Take for example detergents or surface coatings: Based on physical measurements of the observed macroscopic properties of applied coatings and hundreds of calibration formulations, AI-based algorithms can propose the exact ingredients required to reproduce a new coating which exhibits the identical visible color after application on the substrate. Similarly, chemical compounds for tire production can be calculated, or enzyme formulations can be optimized for ethanol production. AI allows R&D to achieve results far beyond what was possible with previous rule-based approaches.

AI can also be used in conjunction with analytics to automate the analysis and interpretation of test series. Those technologies can also be used to conduct intelligent research in literature and patent databases or ELN to support the search for leads for new applications.

4 Tapping into the power of data

For many chemical companies, there may be no clear business case for an AI-equipped supercomputer. However, there are other options that may be less leading-edge, but are nevertheless effective. For example, the integration of laboratory technologies can significantly improve data collection. An IT infrastructure that integrates laboratory information management systems (LIMS) and ELNs can enable companies to gather R&D data into data lakes- centralized collections of large amounts of data that can be readily accessed by employees. In addition, a variety of tools make it easier to use data. Semantic search and chemical entity extraction can help identify relevant documents containing chemical structural information in text form, such as patents, or develop insights from unstructured presentations. And analytics software can be used to explore data and derive concrete suggestions for structured problem-solving, or to develop inspirations for new products.

But software and data have the potential to do more than inspire chemists. Recently, a research group developed an algorithm that uses deep neural networks to develop retrosynthetic routes to organic compounds. This approach handled nearly twice as many molecules, and worked 30 times faster, than non-AI computer-aided methods. Furthermore, those routes were of such quality that students were not able to tell whether they had been derived by a human or an artificial chemist (Segler, et al., 2018): . The question then is, are we seeing “creative” work being performed by a machine? In time, such algorithms are expected to be able to solve more complex chemical problems and significantly improve today’s computer-aided synthesis planning.

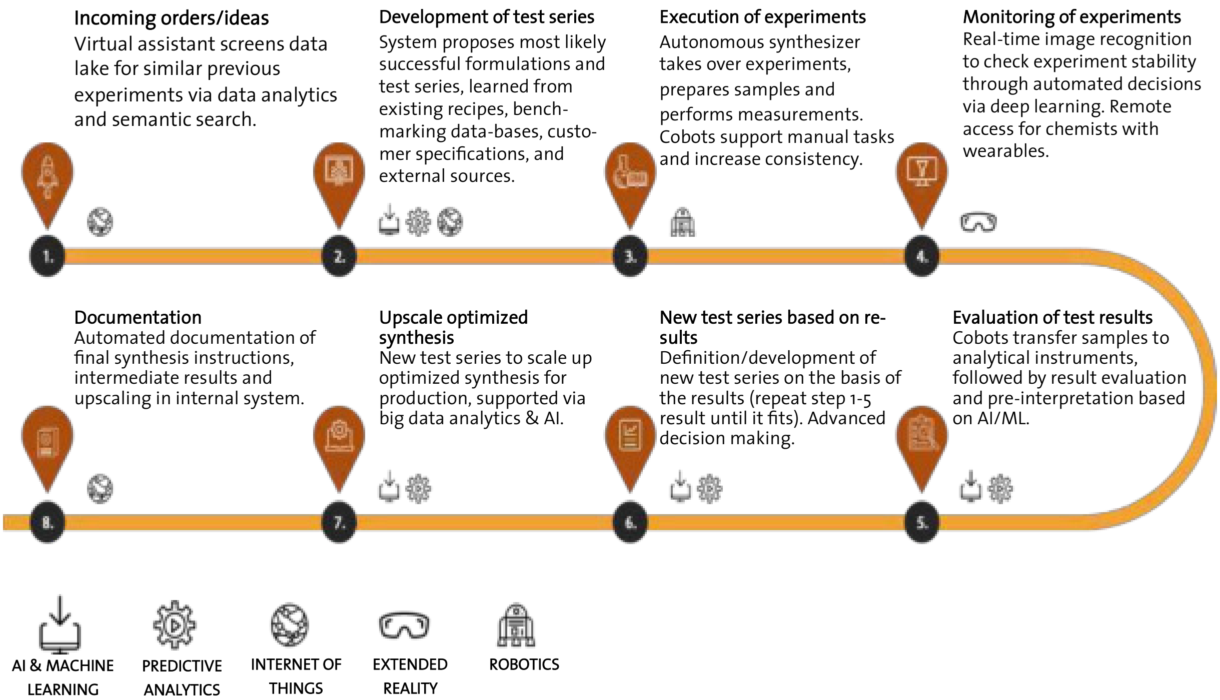
The availability of standardized information on reactions from various scientific databases is fundamental to this type of achievement. Companies can also take steps to leverage internal data more effectively through the use of data lakes- but it is vitally important that only validated data be allowed to enter the lake. Today, the process of data validation can be easily automated at the point of ingestion with the help of AI. In addition, the integration of knowledge from external sources, such as literature or patent databases, can augment the use of internal data in R&D. Overall, these efforts can make it possible to work with uniform data in laboratories at multiple geographically dispersed locations. This can make R&D faster and more cost-efficient, and shorten the innovation process by up to 15 percent, increase project throughput and considerably improve time-to-market (Accenture, 2018).

5 Taking lab automation to the next level

New automation technology has the potential to further raise productivity, standardization and reproducibility in the lab. For example, collaborative robots, called cobots, can supplement the work of humans, physically interacting with them in a shared workspace. Cobots are typically used for easy, monotonous and repetitive tasks. Unlike larger industrial robots, they can work in a safe and interactive manner without being “caged” and segregated from employees. In addition, cobots can adapt to real -world variability and are agile enough to be modified for different applications quickly. They perform their tasks without the errors associated with human work, and with greater speed and precision. They can, for example, reduce standard deviation when conducting specific experiments to one third of that typically seen in human work, while making globally determined test results comparable and more reproducible. Also, cobots can be manually set up and trained by non-engineers within minutes. Cobots are already freeing up R&D employees from repetitive tasks in some chemical company labs, and they are likely to be more and more common in the near future. Indeed, the overall industrial cobot market in 2020 is expected to be 10 times the size that it was in 2015, making it one of the fastest growing markets in the robotics space (Twentyman, 2017).

The use of cobots will be just the beginning, and lab automation will soon go far beyond simple tasks such as standardized injection of samples into measuring instruments. Take, for example, recent research results published by the University of Glasgow: A robotic laboratory platform equipped with a chemical reaction protocol compiler, based on the translation of commonly reported organic reactions, was able to produce three pharmaceutical compounds without any manual interaction. The platform covers all synthetic laboratory processes- from reaction to workup, isolation and purification of the product- and the yields and purities of products and intermediates are comparable

Figure 2 Potential automated process (source: own representation).



or even better than those achieved in traditional manual syntheses. The ability to track the work digitally greatly enhances reproducibility, as well (Steiner, et al. 2019).

Looking ahead, that type of system could be combined with cobots to automate the transfer of product samples to analytical equipment and testing processes (see Figure 2). Using AI to interpret results (which is already being done in some cases today) and using sensors for real-time measurements could enable a completely autonomous synthetic laboratory that could iterate and supervise reaction procedures until a verified route to a desired compound has been developed. Chemists could run and oversee experiments via remote access and augmented-reality tools from anywhere in the world, while robots prepare and run experiments 24/7. What's more, shorter product development cycles could be achieved through integration of data analytics and machine learning and by making optimized processes and chemical analytics easily available in form of a digital code. The future is clear, and close: With advancing digital technologies, a fully autonomous lab is not a distant vision but something that is very likely to become reality soon.

6 Further development of employees is crucial

There is no doubt that digitalization and automation will revolutionize R&D work. However, chemical companies moving to Laboratory 4.0 need to look beyond the technology itself. It is vital to incorporate employees in the transformation process and implement cloud and analytics solutions that are centered on the user- in this case the researchers/ lab technicians. Only then will users embrace new technologies as an opportunity to drive effectiveness and success, rather than regard it as a threat to their jobs. In addition, companies will need "translators"- specialists who are able to understand the functionality desired by chemists and translate it into technical requirements that can be understood and processed by the IT staff. At the same time, companies will have to expand their already-emerging teams of data scientists in order to make the best use of data, AI and analytics. Ultimately, the job descriptions for all R&D staff will continue to evolve, as technology and data knowledge become increasingly interwoven with traditional lab work.

7 A call for action: From lighthouse projects to transformation

Like other enterprise functions, R&D can now benefit from the technological revolution. Therefore, it is crucial that chemical companies provide appropriate IT structures and platforms to enable digitalization, AI and automation. But companies that want to bring laboratory digitalization to a higher level need to move beyond lighthouse projects. Often, companies remain in the stage of digital experimentation for too long with efforts limited to isolated proof-of-concept studies or pilot projects. Instead of such incremental change, they should pursue systematic transformation based on a tailored strategy for the standardization and industrialization of digital activities. The associated scaling up of digitalized processes will require a close collaboration between the IT and R&D departments.

Those companies that remain at the level of individual lighthouse projects are facing the risk of creating unwanted complexity, duplicating effort and resources and leaving potential value on the table. Conversely, if investments are made wisely, with the focus on transformation, companies can position themselves to use digital and AI technologies to drive creativity- and revolutionize chemicals R&D.

References

Accenture (2018): Digital disruption in the lab: The case for R&D digitization in chemicals, available at https://www.accenture.com/_acnmedia/PDF-86/Accenture-Chemicals-Blog-Digital-Disruption-Lab.pdf, accessed 19 March 2019.

Segler, M.H., Preuss, M. and Waller, M.P. (2018): Planning chemical syntheses with deep neural networks and symbolic AI, *Nature*, **555** (7698), p.604.

Microsoft Corporation (2018): *The Future Computed- Artificial Intelligence and its role in society*, available at https:/news.microsoft.com uploads/2018/01/The-Future-Computed.pdf, p. 38, accessed 19 March 2019.

Steiner, S., Wolf, J., Glatzel, S., Andreou, A., Granda, JM, Keenan, G., Hinkley, T., Aragon-Camarasa, G., Kitson, PJ, Angelone, D., Cronin, L. (2019): Organic synthesis in a modular robotic system driven by a chemical programming language, *Science*, **363** (6423).

Twentyman, J. (2017): *IIoT and the rise of the cobots,* available at https://internetofbusiness.com/iiot-rise-cobots/, accessed 09 April 2019.

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Commentary

The relation of energy value chains, global GDP and CO_2 taxes

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1 Introduction

Nature and human beings - as part of nature - depend on a continuous flow of energy to stabilize a state far off any thermodynamic equilibrium. Evolution has addressed this energy demand over millions of years especially by photosynthesis in highly delocalized and dispersed natural systems. In addition, the development of mankind during the last 10,000+ years has also been the quest for new energy sources. Whilst the energy content of wood, wind and water was used wherever possible based on existing or newly developed technologies, societies had also exploited animal powered techniques and slavery more or less until the industrial revolution started in the 17th century. With the utilization of coal first and thereafter oil and gas as well as nuclear power, energy became available in a much higher order of magnitude. Finally, today's world has been built on the combination of sophisticated technologies leveraging as high as possible energy content in primary energy sources. Only recently, mankind has learned to tap into the most ubiquitous energy available on our planet: using sunlight directly for the generation of electrical power via photovoltaic cells and, more indirectly, wind to drive wind mills, which have already reached a MW scale per installation.

The consumption of fossil energy sources over time has reached a level of 11.7 Giga tons of oil equivalents (Gtoe)[1] in 2018. This in turn has resulted in a significant depletion of the world's resources, which nature had generated over hundreds of millions of years. And finally, the excessive burning of fossil fuels has contributed significantly to rising CO_2 levels in our atmosphere, leading to the current situation, which can only be considered as highly unsustainable.

Many initiatives on international and national levels, foremost the United Nations Sustainable Development Goals (United Nations, 2015) and derived thereof the climate protection conferences including the Paris Agreement from December 2015 (United Nations, 2015b), tried to create a sense of urgency and to define and implement measures to limit green house gas emissions.

Fact is, that over the last 27 years since Rio 1992 none of the agreed measures have achieved the goal to limit emissions. On the contrary, emissions in absolute terms have increased ever since. Unfortunately, there are reasons for that pattern stemming from the global economic development in combination with our global monetary system. The relation and influencing factors are outlined below. Key words are energy value chains, energy consumption and GDP, monetary system, climate debate and finally perspectives.

2 Energy value chains and well being

In the chemical industry so-called value chains from crude oil to plastic materials, active ingredients or pharmaceuticals are familiar descriptions of material flow, which can also be the basis for designing a circular economy (Kopel and Utikal, 2019). However, circular economy cannot be expected to solve our resource problems alone. The reason for that is often the neglect of the energy part, which is needed to make material value chains and circular economies work.

[1] Energy units and conversion: 1 toe ≅ 1,2 kNm^3 ≅ 1,5 SKE ≅ 12 MWh ≅ 42 GJ; toe: ton of oil equivalent; Nm^3: standard cubic meter; SKE: coal equivalent; MWh: megawatt hour; GJ: Giga Joule; Giga: billion

Considering energy as an integral part of our life and the basis for our well-being, it becomes quite obvious that everything just depends on availability and distribution of energy (here called the energy value chain). On each step of the material value chain, energy in various forms is needed. Ore refinement to steel requires energy (fuel and electrical power) for the machinery park that is digging, extracting, transporting, purifying, processing and finally forming of steel plates. The same is true for aluminum production and for all other materials required in our world including agricultural products. In the chemical industry and along the chemical value chains additional energy input is needed to build the broad portfolio of chemical products often starting with crude oil as the major feedstock. Moving forward in the value chain towards the consumer products the same logic applies. Energy input is needed for transportation, heating of industrial buildings, running machinery based on electrical power and again logistics to serve the next customer level in the value chain. Finally, materials or products get either consumed in the industrial manufacturing processes itself or by the consumer. At the end of the useful lifetime of a product, energy is again needed for collecting, purifying, sorting, recycling (to close the material loop but not the energy loop!) or for appropriate disposal.

Bottom line, on each step of our chemical and industrial processes, the industry uses energy, predominantly in the form of fossil primary energy sources, which are crude oil, coal, natural gas and fuels derived thereof. Materials can be regarded as "frozen energy" with a certain lifetime, having been produced at a certain point in time based on raw materials supplied by nature and using the energy mix at their specific date of production. This is true for the pyramids of Giza in Egypt (mainly man/animal power) as well as for modern smartphones or any other product of our industrial processes. The energy used is not only captured in these products as such but also in transportation, heating and everything needed to manufacture the product. This part of the energy is dispersed and cannot be recuperated. Concepts around the circular economy are often neglecting this major part of energy consumption.

Going one step further, one could argue that also private income, e.g. salaries paid to the workforce in the global economy, is more or less immediately converted into energy consumption (heating of private homes, mobility, consumer products, etc.). This thought will be taken up later in this article in more detail.

In essence, no other input factor than energy is needed to run the global economy. With sufficient energy available it is easily possible to extract Lithium (needed for batteries) from sea water, ores from less productive deposits, drinking water from sea water in desalination plants and closing recycle loops in the circular economy including activation of carbon dioxide, just to name some examples. Notwithstanding the above, one factor is obviously needed in addition: know-how to use energy efficiently, being an area with significant progress during the last decades.

3 Global energy consumption - historically and outlook

With the understanding that essentially only energy matters, a view on the global consumption and supply pattern over the last 55 years supplemented by an outlook until 2040 reveals the full scope of the challenge we are facing (Figure 1).

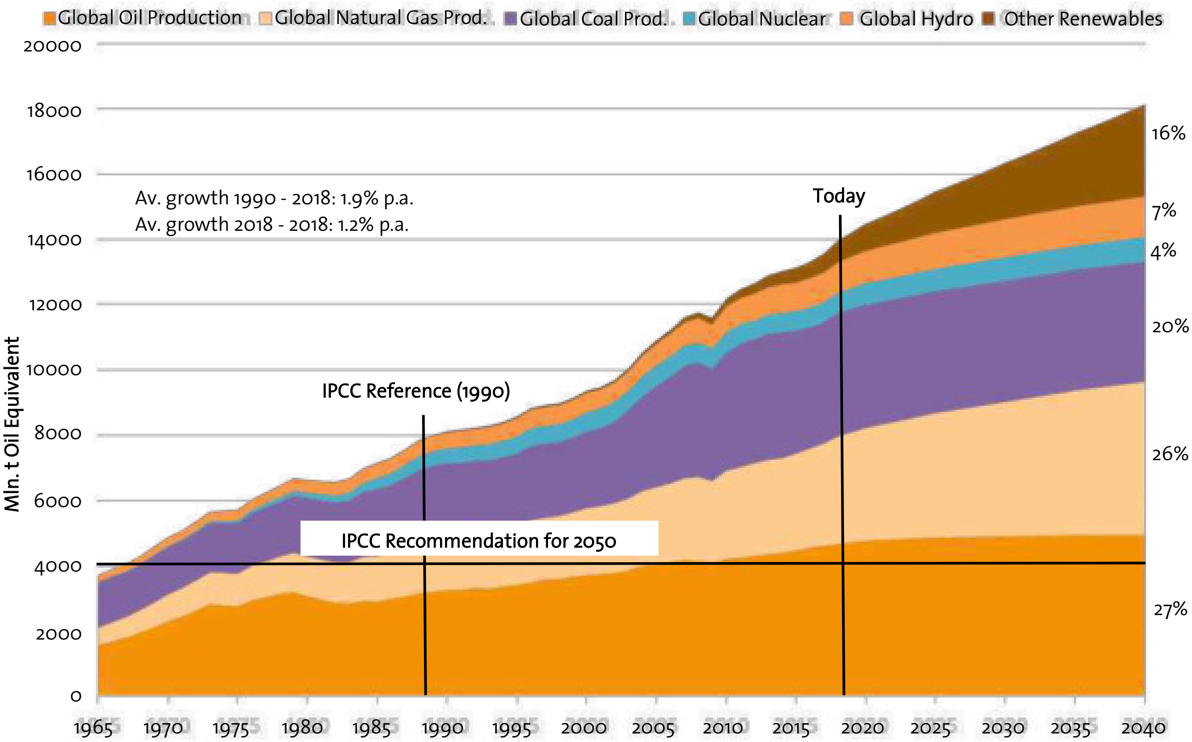
In 2018, global energy consumption had reached a level of 13.9 Gtoe. Crude oil contributed with 4.6 Gtoe (33%), natural gas with 3.3 Gtoe (24%), coal with 3.8 Gtoe (27%), nuclear power with 0.6 Gtoe (4%) and all renewables together with 1.6 Gtoe (12%). Despite its presence in political debates and the media, biofuels only contributed with less than 1% to global energy supply. The average demand growth since 1990 has been rather constant at 1.9% p.a., which shows the same trend as global GDP growth. Looking a bit more closely, there are only short periods when energy demand growth was stable or even decreasing. All these periods were associated with either supply side restrictions, respectively massive price increases (e.g. the oil crises in 1973 and 1979/1980), or lack of global economic growth (such as in the early 1990ies) or again very high oil prices followed by a consumption crisis during and after the financial and banking crisis of 2008/2009. The conclusions from such pattern will be discussed below.

Expectations for the future are worrying. There is no reason to assume that the energy demand trend will change significantly. Climate protection programs could not reverse this global trend in the past. In addition, the demand and supply patterns, which are based on infrastructure and industrial investments over decades can hardly be adapted within the next 20 to 30 years, keeping in mind that for example coal fired power plants, which have driven China's and in general Asia's economic growth since the year 2000, have useful lifetimes of 50+ years. The energy demand forecast, based on a scenario which assumes that government policies, technology and social preferences continue to evolve in a manner and speed seen over the recent past, shows a 1.2 % increase p.a. for the next 20 years. Despite a very significant increase of non-fossil energy globally (plus 2.8 % p.a. 2018 to 2040), also fossil fuels are expected to grow in absolute terms (from 11.7 Gtoe in 2018 to 13.2 Gtoe in 2040 or 0.6 % p.a.). Now, it is very obvious that the Intergovernmental Panel on Climate Change (IPCC) recommendation, requesting a reduction of 50% relative to fossil fuel consumption in 1990 or – in other words - going back to the level of consumption in the late 1960ies, will be largely missed on a global level. The situation varies between the regions.

The North American continent with US, Canada and Mexico (Figure 2) is heavily relying on fossil fuels. Demand peaked in 2018 with no meaningful increase in the share of Renewables in the energy supply mix. Very obvious, the impact of shale oil and gas has led to a dramatic decrease in fuel import requirements. The continent has turned into an export region.

EU28, as a region with a significant lack of own fossil energy sources, shows a different pattern (Figure 3). Energy demand peaked in 2006 and decreased in the aftermath of the economic crisis 2008/2009. With economic growth picking up in most of the EU countries since 2013 and specifically in Germany, energy demand has turned into growth mode again. Dependency from imports remained stable at close to 60 % despite the significant increase in renewables, mainly in Germany, which only just compensated for shutdowns of some coal and nuclear power plants. The growth in energy demand has been covered by additional natural

Figure 1 Global energy demand and supply (source: own representation based on BP 2019; BP 2019b).



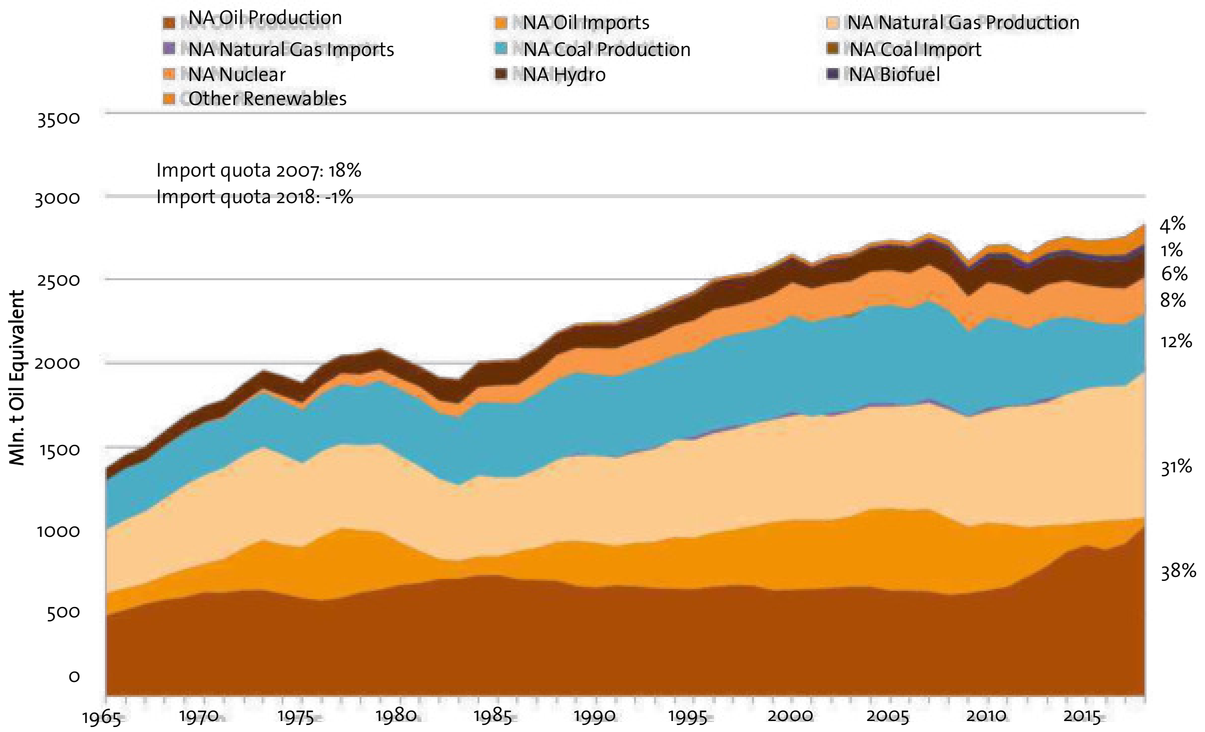
gas imports.

China's energy demand has increased dramatically parallel to its impressive economic development starting in the late 90ies (Figure 4). While in the beginning the energy demand was covered by own coal resources, including the transformation of coal into chemicals and fuels based on coal to gas processes, China has started to diversify its energy supply base. China is specifically importing liquid fuels for its heavily growing transportation sector. Interestingly, China has largely absorbed the Middle East crude oil production, which did not find its home in the US following the shale oil and gas boom. Without shale oil/gas we would have seen much higher crude oil prices in the past. As part of the diversification strategy, China is also heavily investing in hydro power and Renewables. Over the last 20 years China contributed the largest share to global CO_2 emissions based on its fossil fuel consumption, from which in turn the global economy profited through low priced energy intensive products such as construction steel, plastics, chemicals, aluminum, etc. Specifically the US and Europe have benefitted from externalization through using China as a lower cost manufacturing base ("globalization").

Will global energy demand stabilize on the current level? No! India, the rest of Asia and the African continent are determined to follow the other regions in terms of energy requirements. This development is in particular in line with a number of UN Sustainable Development Goals (Goal 1: End poverty in all its forms everywhere; Goal 7: Ensure access to energy for all, e.g. foster economic development of 1.2 billion people without electricity or 2.7 billion people without clean cooking fuels).

To complete the picture, a holistic view on the primary energy consuming activities is necessary: in a rough approximation, three quarters of the primary energy is needed to run the global economy and provide all elements of the desired increase in prosperity on earth. Only one quarter ends up directly with the end consumer supporting her or his well-being, such well-being means i.e. having access to heating/cooling/lighting of private homes, fuels to travel from A to B, a wide variety of food and consumer products, benefiting from health care and medication, having access to information

Figure 2 North America energy demand and supply (source: own representation based on BP 2019; BP 2019b).



and data services, living in a secure and protected environment, enjoying cultural activities (sports, music and art) and supporting science.

It is important to note, that the three quarters needed to run the global economy are the precondition for the wealth of each individual. The

Figure 3 European (EU28) energy demand and supply (source: own representation based on BP 2019; BP 2019b).

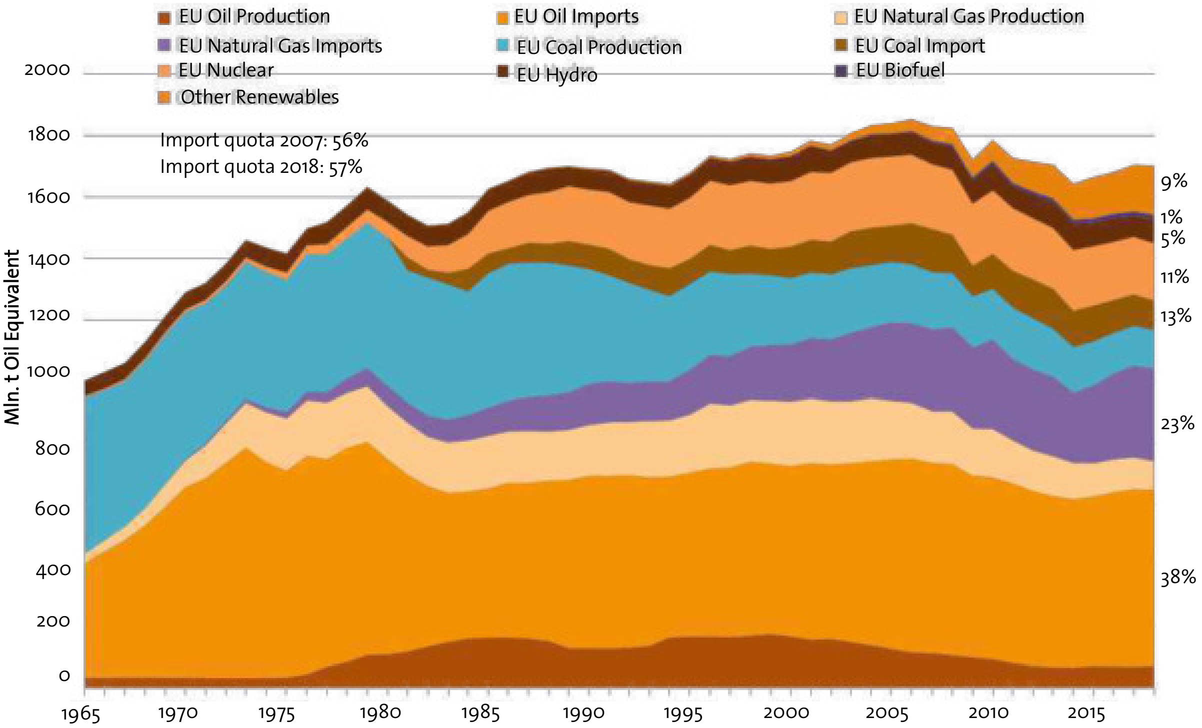
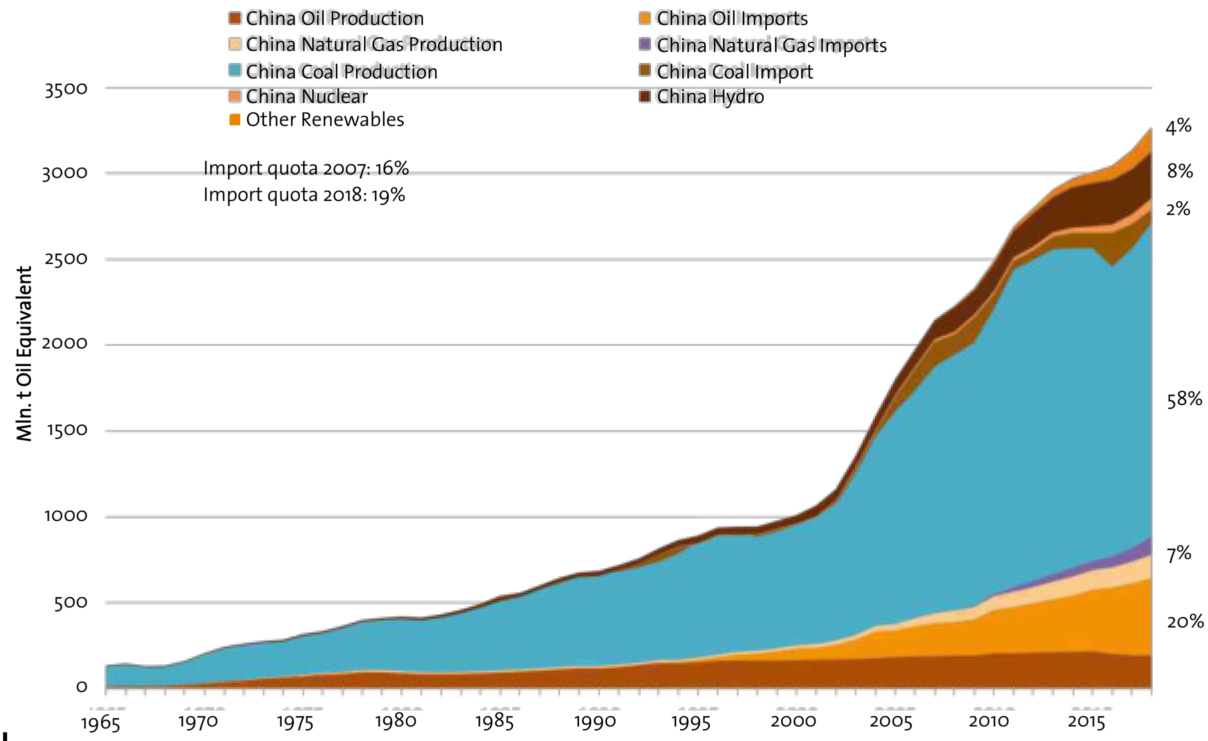


Figure 4 China energy demand and supply (source: own representation based on BP 2019; BP 2019b).



one goes hand-in-hand with the other.

Could efficiency change the picture? Up to now: again No! Until today, in most human activities increasing efficiency has often been (over-)compensated by larger living space per person, increased passenger kilometers, higher quality products, standards and services (technological advancements in automobiles over time may serve as an example).

4 GDP and energy demand

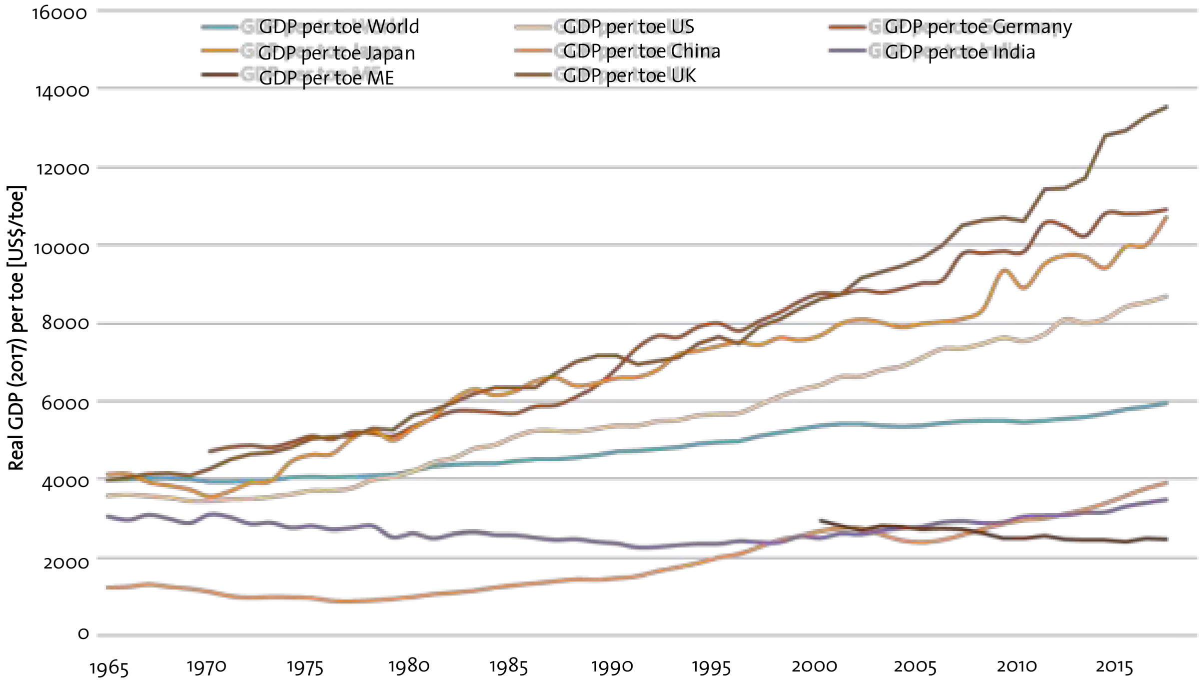
Under the assumption that only energy is driving our global economy, global GDP (80.7 tn US$ in 2017) (Table 1) can be directly linked to the global energy demand of 13.5 Gtoe in 2017. The global GDP value created by one toe was around 6000 US$ in 2017. Figure 5 represents the development over time based on real US$ (2017). On a global level the desired decoupling of GDP from energy demand cannot be observed. Over 20 years, GDP per toe increased by only 0.7 % p.a.

On the one hand, countries like Germany or Japan have improved the ratio over time and produce a higher GDP per toe than other countries. The reason behind are efficiency gains (higher utilization in key industries and infrastructure, energy saving measures, e.g. insulation of renovated homes or low energy homes

Table 1 Overview GDP 2017 (source: own representation).

Country/region	GDP 2017 (tn USD)
Global	80.7
US	19.4
China	12.2
Japan	4.9
Germany	3.7
UK	2.6
India	2.6
ME (KSA, USA, Iran, Kuwait, Qatar)	1.8

Figure 5 GDP intensity per toe 1965 - 2017 (source: own representation).



when newly built) but also externalization of energy consuming industries (refineries, steel and chemical industry, etc.). On the other hand, countries such as China and the Middle East have built up such energy intensive industries. Consequently, GDP per toe in these countries are significantly below global average.

Also from a theoretical point of view there is no reason to assume that a decoupling could be possible. Major efficiency gains in the past came from economy of scale and automation. These effects were partly compensated by depletion of low cost resources (e.g. substitution of crude oil production costs of 50 cts/bbl in the Middle East by 30+ US$ per bbl from shale oil or Canadian tar sands), increased quality of products (e.g. automobiles, machinery), higher standards across all economic activities and more transportation (also as a result of globalization).

The consequences of the direct correlation between GDP and energy demand are now obvious:

- Any kind of investment or spending, independently whether it is business, government or private, creates energy demand somewhere on the planet.
- Any increase in global GDP and hence prosperity requires additional energy input. The global growth just depends on available energy (only energy limits the global potential growth).
- Consequently, “money” can actually be considered as a license to consume a certain amount of (primary) energy. Remunerations and salaries paid then become nothing else but the right to consume energy, e.g. for heating/cooling of private homes, transportation, purchasing of goods (purchase of “frozen energy”) or paying for services, which allow others to consume parts of the energy needed (e.g. spending money during vacation).
- Global currencies are “backed” by global energy reserves and the availability of those reserves. As long as money supply by the central banks is in line with economic growth based on additionally available energy, there is no fundamental reason for any kind of economic crisis. Prosperity without economic cycles could go on for decades until mankind in total has achieved a certain standard of living. Even an unconditional basic income would be possible on the long run.
- Ownership in invested capital just means control rights over physical assets, which had been produced with a certain energy mix in the past.
- Monetary entitlements due at a certain point in time in the future (e.g. loans, pensions, etc.) are safe as long as there is sufficient energy available at that due date (and the entities that have to pay back the loans/pensions have access to such energy).

5 Consequences for the climate protection debate

A carbon tax of 30 US$ per ton of CO_2 emission or approx. 100 US$ per toe is insignificant compared to the value created by one toe (6000 US$). In business, CO_2 taxes are just incorporated into the price of a specific product. Even worse, taxes paid by one part of the global economy are reallocated to and spent by other entities. With this spending additional energy is consumed and hence the corresponding CO_2 equivalents are emitted elsewhere. Reasonable taxes are an instrument to drive efficiency but not an instrument to reduce emissions in absolute terms. Despite the fact that many countries are not participating in the CO_2 trading schemes, which undermines the concept already, CO_2 taxes cannot fundamentally solve the problem in view of absolute emissions.
There are only two ways to solve the CO_2 problem:

(1) Limit and reduce the consumption of fossil fuels based on binding agreements

To understand the consequences of such an approach, it is important to keep in mind another very significant relation: energy consumption generates GDP and GDP generates workplaces. With this relation in mind, unfortunately no one can have an interest in significantly reducing the energy input into the global economy in a comparatively short time frame (e.g. until 2035 or 2050). Without the continuous flow of energy on today’s level our global society would fall apart. The banking crisis 2008/2009 with a global GDP (and energy) slump of only 5% (energy minus 2%) for just one year is the most recent show case, which demonstrates the vulnerability of our global economy. The Great Depression of the year 1928 - manufacturing decreased by approx. 30%

- is the worst case in recent history with all its disastrous consequences around the globe. IPCC requests a reduction of fossil fuels by 70% until 2050 compared to today's level. Clearly, limitation of fossil fuels without compensation through non-fossil fuels is not an option at all. This leaves only the following path forward:

(2) Heavily invest in renewable energies on a global scale (global "Energiewende")

During the last decade, renewable energies got much more efficient. For wind power plants in Germany energetic amortization can be achieved within 2-7 months and approx. 2 years for photovoltaic systems. Consequently, mankind needs to significantly accelerate investments into these technologies in combination with smart power grids and storage solutions. Mankind needs to invest for a certain period of time a meaningful portion of the global GDP into Renewables. Instead of building tanks, warplanes and reentering into a new arms races, investments in a decentralized energy system could not only contribute to solve the CO_2 problem but also to reduce the major inequality between nations and continents on our planet.

6 Perspective - what needs to be done in addition to existing programs

- The supply side of energy: Provide significantly more financial funds for investments in renewables through involuntary contributions by the wealthy parts of the societies (in exchange for shares in such energy undertakings) and drive innovation in storage systems.
- Demand side of energy: Accelerate all measures to save energy and drive innovation in all areas of human activities to maximize well-being with a minimum of energy consumption (e.g. isolation of buildings, e-mobility, sharing economy, enhance lifetime of products, etc.).
- Avoid destruction of "frozen energy" and activities not supporting prosperity. Ban and eliminate activities incompatible with the climate goals, such as wars, excessive military spending, excessive luxury, private flights into space, etc.
- Communication strategy: Explain the relation between money spending, energy consumption and CO_2 emissions to our societies and create awareness in all parts of a society.
- Transparency on CO_2 emissions: Establish a CO_2 account (like a bank account) for each and every person on the planet, which collects CO_2 emissions triggered by the personal lifestyle. This personal account should create visibility and a sense of urgency on a personal level; all CO_2 emissions, also the ones from the global economy need to be allocated to the end consumer, who is finally responsible for all the impact of her/his consumption pattern.
- Intensify research along the lines outlined above: Further develop the concept of energy value chains in more detail and adjust the established macro economic theories and specifically growth theories (not labor, capital and innovation define the boundaries but just energy availability and innovation). Describe the relation between GDP, primary energy consumption and workplaces. Develop concepts to distribute work amongst a growing world population with a higher degree of automation (digitalization) and less energy input. Provide for statistical data to describe the efficiency of our global world in detail (Input: Primary energy sources; Output: Well-being).

7 Summary

The article presents a holistic view on our global energy supply/demand situation and argues that in today's world, economic activity and hence our prosperity is just primary energy consumption (besides the knowledge to utilize such energy). This fundamental understanding allows to link energy consumption directly with economic and financial development and vice versa. Each and every US$, Euro, Yen, etc. spent or invested creates energy demand, secures workplaces and, unfortunately, causes also CO_2 emissions, which stem from the 85 % fossil fuels in the global primary energy mix. All economic activities require energy input and, consequently, any economic growth results in even higher energy demand. On a global level, a decoupling of GDP and energy consumption is neither obvious in available data (except for some efficiency gains) nor does it have a theoretical justification. As a result global energy demand will continue to grow and can be expected to even outpace the ambitious implementation plans for renewable energies. Based on today's economic growth expectations and political concepts, fossil energy demand must be expected to grow further leaving no realistic opportunity to achieve IPCC goals by 2050. The only way forward is a) a very significant increase of renewable energy (especially from wind and photovoltaics) and b) to create transparency in CO_2 consumption for each and every person on the planet. The author opts for a radical new way of thinking along the lines of Energy Value Chains and associated CO_2 generation, involuntary investments in renewable energy funds by the wealthy parts of our societies, measures to create transparency on CO_2 emissions associated with personal life style and a significantly better communication of related facts across our global society.

References

BP (2019): *BP Statistical Review of World Energy*, available at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf, accessed 19 June 2019.

BP (2019b): *BP Energy Outlook 2019*, available at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf, accessed 19 June 2019.

Frauenhofer Institute for Solar Energy Systems ISE (2018): *Aktuelle Fakten zur Photovoltaik in Deutschland*, dated 21 February 2018, available at https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf, accessed 19 February 2019.

Kopel, T. and Utikal, H. (2019): Zirkuläre Wirtschaft – Eine reale Geschäftschance, *Nachrichten aus der Chemie*, **67** (Februar 2019), pp. 27-29.

United Nations (2015): *United Nations General Assembly Resolution A/RES/70/1, Transforming our world: the 2030 Agenda for Sustainable Development*, available at https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf, accessed 19 February 2019.

United Nations (2015b): *The Paris Agreement*, available at https://unfccc.int/sites/default/files/english_paris_agreement.pdf, accessed 19 February 2019.

World Bank (2018): *World Development Indicators*, available at https://databank.worldbank.org/source/world-development-indicators, accessed 19 February 2019.

Practitioner's Section

How digital tools make circular economy operational in industrial areas: The example of BE CIRCLE

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Industry is facing growing pressure to reduce greenhouse gas (GHG) emissions and waste by regulation. Circular economy principles can be used to optimize resource flows in industry. However, industry still faces concrete financial, regulatory, technological, and organizational barriers to do so. For the establishment of industrial synergies, ecosystems can be seen as a useful concept to frame and implement circular economy principles. New digital tools can support the implementation of circular economy projects, which use field and publicly available data. In this article, we present "BE CIRCLE" as an example for digital services that help to identify new opportunities to cut GHG emissions by closing resource loops. During the development of BE CIRCLE, three case studies with two industrial parks and one port were conducted. The outcomes and learnings are described. In addition, recommendations for data management will be proposed.

1 Introduction

Industry is facing ever growing pressure to reduce greenhouse gas (GHG) emissions and waste. Circular economy is seen as one valuable way to address these issues. The Ellen MacArthur Foundation (2015) estimates that € 1.8 trillion of net economic benefit by 2030 can be created thanks to circular economy initiatives. Circular economy principles can be used to optimize and drive industrial developments. For instance, they can be implemented in industrial parks and eco-industrial parks (EIPs). Indeed, circular economy initiatives still face concrete financial, regulatory, technological, and organizational barriers. A new generation of digital tools is being developed, which can help to overcome these barriers. Therefore, this article includes the following four contributions.

First, this article starts with highlighting the importance of circular economy for industry. Then, it explains the concept of circular economy and industrial synergies. In this context, ecosystems are presented as a relevant space to implement industrial synergies. Subsequently, challenges and barriers for the implementation of circular economy projects are enlisted.

Second, a new generation of digital tools will be described, which use field and publicly available data. These digital tools can help to overcome the identified barriers for implementing circular economy projects.

Third, BE CIRCLE is shown as an example of the latest generation of digital solutions and three case studies are described including their context, the project and the respective outcome plus learnings.

Fourth, recommendations will be given what should be considered while using data for circular economy projects.

2 Why circular economy matters for industry

The reports "The Limits to Growth" (Meadows et al., 1972) and Rockstrom's article (2009) raised high public awareness about the finite supply of natural resources. This has led to several changes in policy and regulation. As a consequence, industry is facing growing pressure to reduce resource consumption, GHG emissions, waste and other environmental impacts (e.g. European Union Emissions Trade Scheme (EU ETS)). In the same time, local authorities try to develop sustainable areas such as EIPs. EIPs can be defined as a dedicated area for industrial use at a suitable site, which ensures sustainability through the integration of social, economic, and environmental quality aspects into its site planning, management and operations (Lowe, 1997). Today, worldwide about 250 EIPs are currently operating or under development as opposed to fewer than 50 in the year 2000 (World Bank group, 2017).

Concerning the measurement of industry's environmental impact, end-of-pipe solutions were the first measures, which were introduced to control and treat pollutions in production. Subsequently, cleaner production practices have been implemented to prevent or reduce pollutions by optimizing processes, which then require less resources input and output, or substitute toxic through non-toxic materials or use renewables. The latest environmental solutions are more systemic including lifecycle thinking and have the aim to close production loops within an industrial ecology like EIPs (OECD, 2009).

Therefore, industry managers must develop long-term strategies that integrate the triple bottom line (TBL) in their activities and business models, which combines the 3 Ps including People (social layer), Planet (environmental layer) and Profit (economic layer) (Joyce & Paquin, 2016). For this reason, industry managers must develop solutions that are consistent with people's behavior, consider the limited resources of the planet and that are efficiently and economically produced.

2.1 A useful concept to change production modes

In this context, the concept of circular economy has emerged during the last 20 years as a promising response to these challenges (Lieder and Rashid, 2016), while regional and national policies have included circular economy in their political agenda (e.g. European Union Circular Economy Package and China's Circular Economy Promotion Law). In contrast to the predominant linear economy, in which continuous growth is based on an increasing resource extraction and follows the logic of "take, make, and waste", the circular economy is a successful paradigm shift (Geissdoerfer et al., 2017) and an attractive management concept to change production modes in industry (Preston, 2012). It is the "realization of closed loop material flow in the whole economic system" (Geng and Doberstein, 2008) aiming at the decoupling of growth from resources. The route to a sustainable economy leads to a closed-loop system where nothing is allowed to be wasted or discarded into the environment, which reuses, repairs, and remakes in preference to recycling (Bocken et al., 2014). The system must be built on collaboration and sharing, and emphasizes delivery of functionality and experience instead of product ownership.

2.2 How to build ecosystems for circular economy: Industrial synergies

Many companies are located in industrial areas or parks interacting with multiple stakeholders and other companies while exchanging products, resources, and services (Zeng et al., 2017) within what can be called an ecosystem. A business 'ecosystem' can be seen as a structured community of organizations, institutions, and individuals that impact the firm and the firm's customers and suppliers (Moore, 1993; Teece, 2007). The ecosystem of an industrial firm includes competitors, complementors, suppliers, regulatory authorities, standard-setting bodies, the judiciary, and educational and research institutions and it has major impacts on the firm's competitiveness (Teece, 2007). Hence, the ecosystem perspective is a suitable framework to implement circular economy approaches. An ecosystem can be implemented through industrial synergies (IS)[1], in which geographically close industries can develop a competitive advantage by the synergetic exchange of materials, resources, energy, water and by-products (Chertow, 2000). IS are concerned with closing material streams and loops by using wastes from one facility as an alternative input for another facility (Van Berkel et al., 2009).

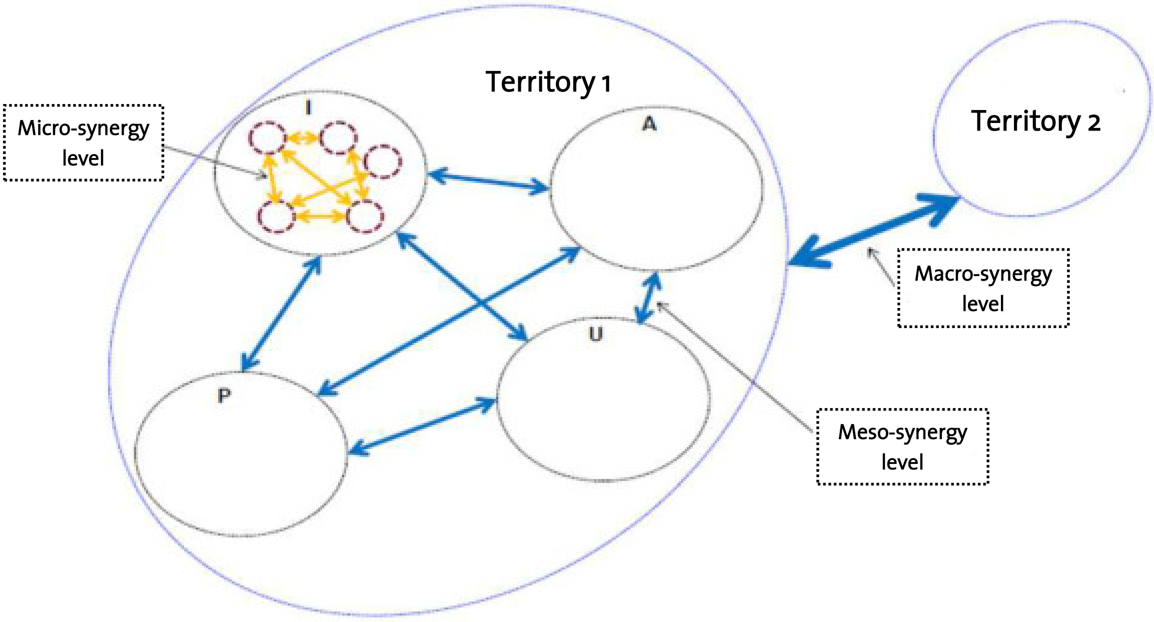
Industrial parks can be considered as an ecosystem consisting of various stakeholders exchanging resources and creating industrial synergies. In an industrial park, circular economy approaches can be implemented at three different levels that correspond to their spatial scope (Mat, 2015). First, the firm's level is the micro-level (e.g. the production plant). Second, the local ecosystem is the meso-level (e.g. industrial park), and third, the regional ecosystem is the macro-level (e.g. region). Spatial proximity and the possible connections define the type of synergies that can be implemented. At the firm's level, micro-synergies are implemented within one production plant. At the industrial park's level, meso-synergies can be implemented through the exchange of resource flows between different firms. At the regional level, other types of synergies can be implemented beyond the local borders of the industrial park. The three different types of synergies are summarized in Figure 1.

According to Boons et al. (2017), several types for the establishment of industrial synergies can be identified and characterized by the initiating actor(s), their motivation and typical outcomes (see Table 1). Local governments and/or industrial stakeholders can elaborate a strategy for the development of an eco-cluster or EIP. In this participatory process, which involves multiple stakeholders, symbiotic linkages between the different stakeholders are identified and developed. This process aims at the (re-)development of areas, brownfields, greenfields, and innovation clusters and is part of a broader strategy for eco-innovative solutions.

2.3 Relevant ecosystem stakeholders for industrial synergies

Ecosystems and IS link different categories of stakeholders that work and influence each other. These categories include private stakehold-

Figure 1 Different levels of synergies (source: Mat, 2015).



[1] Industrial synergies refer to the operationalization of the paradigm of industrial ecology through closed-loops of matter and energy (Dumoulin and Wassemaar, 2014). Industrial synergies are defined as physical exchanges of materials, energy, water, and by-products among diversified clusters of firms (Chertow, 2007). They engage diverse organizations in a network to foster eco-innovation and long-term culture change (Lombardi et al., 2012). In this article, we use industrial synergies as a generic term for flows and material exchanges. Industrial symbiosis and industrial synergies are comparable terms, especially when used by practitioners (e.g. Huber and Corma, 2007).

Table 1 Different types of industrial symbiosis including their initiating actor(s), their motivation and typical outcomes (source: Boons et al., 2017).

Type of industrial symbiosis	Initiating actor(s)	Motivation of the initiating actor(s)	Typical outcomes
Self-organization	Industrial actor	See economic and/or environmental benefits from IS	Agglomeration Hub-and-spoke network Decentralized network
Organizational boundary change	Industrial actor	Eco-efficiency and business strategy	
Facilitation-brokerage	A public or private third-party organization	Establish/increase transparency of market for firms to develop IS	One-off network of symbiotic exchanges
Facilitation – collective learning	A public or private third-party organization	Enable firms to develop tacit knowledge and exchange experiences	
Pilot facilitation and dissemination	A public or private third-party organization	Learn from nonlocal existing IS cases and experiment in a local context	Diffusion of IS concept among clusters
Government planning	Governmental actor(s)	Learn from existing IS cases and implement	
Eco-cluster development	Governmental and/or industrial actor(s)	Innovation, economic development	Redevelopment Brownfield development Greenfield development Innovation cluster

ers and public local authorities. For instance, they are firms, industrial park planners and developers, industrial park operators and management, industrial or business associations, chambers of commerce, regional and local governments, and funding agencies (World Bank Group, 2017).

The different stakeholders of the ecosystem can consider and plan their activities according to three different time horizons: (1) operational planning (short-term reaction to a declared urgent situation), (2) technical planning (middle-term strategy of precaution in response), and (3) strategic planning (long-term ambition in order to provide needed changes) (Mat, 2015).

Each stakeholder has distinct needs according to their respective position in the value chain and function. This depends on the kind of networks and resource flows which they have to manage. At the micro level, industrial managers pursue mainly cost and production control strategies. At the meso level, network and utilities managers need to optimize and develop further their infrastructure while ensuring everyday operations of their network's users. At the macro level, industrial park managers and developers try to attract new industries and find connections and synergies either at the local level or beyond the industrial park's borders.

In general, industrial stakeholders mainly focus on cost savings in terms of reduced material and energy prices, which represent strong incentives to engage in synergy search. Besides, an increasing market demand for green solutions provides an incentive to engage into the development of sustainable solutions - what could lead to a higher market share when offering green solutions (Porter and van der Linde, 1995; Triguero et al., 2013). Finally, industrial stakeholders must consider changes in regulation as the introduction of new standards may require the development of environmentally friendly solutions and to avoid penalties or higher taxes (Triguero et al., 2013).

In contrast to industrial stakeholders, local and regulatory authorities, economic development agencies or associations have a strong interest to (re)develop brownfields and greenfields, industrial areas and parks to increase the attractiveness, competitiveness and employment of their region (Boons et al., 2017). They pursue rather social and economic goals. They promote the sustainable use of land with different scopes (single plot of land vs. larger area like an industrial park) and work within different timeframes (e.g. short term synergy matching vs. long term infrastructure planning). Furthermore, they seek to favor better working and labor conditions, direct and indirect employment creation and support technology and knowledge transfer through investments (World Bank Group, 2017).

Therefore, each stakeholder may need and develop different capabilities. In the context of a circular economy, cooperation and being part of a network becomes increasingly important (Boons et al., 2017). Industrial stakeholders can develop technological and management capabilities, implement collaboration with research institutes, agencies and universities to access external information and knowledge to push the development of technological solutions (Triguero et al., 2013).

2.4 Challenges for relevant ecosystem stakeholders

For the build-up of an ecosystem, stakeholders must take into account the following challenges:

First, delineating the potential playground for circular economy projects and identifying the relevant stakeholders may be difficult. It is sometimes hardly possible to see where producers and emitters of resources are located in order to discuss circular economy approaches in an (industrial) area or region. This is often the case when a stakeholder does not know the respective area very well. Available resource flows must be quantified and visualized to enable discussions with other relevant stakeholders. In particular, industrial park managers and especially the public entities in charge of economic development have a certain interest to build the industrial fabric of an area or region. They must develop long-term strategies to complete their vision and knowledge of the industrial area or region, which they manage. This is also useful for their territorial marketing activities to show the attractiveness of an area or region. For instance, a crucial task for them is the pooling of resources and transport to achieve modal shifts. Concerning the attractiveness of an industrial park, industrial park developers need to deliver high quality services beyond land sales or rent for potential clients. In industrial areas, network operators must be able to identify additional renewable or recovery supply for resources to increase the environmental performance of their offer in order to comply with local regulations and to respond to their clients' needs.

Second, field and publicly available data must be gathered for the visualization of the ecosystem. Bundling information from different databases is a real challenge, which calls for specific competences and tools (e.g. geographical data analysis for industrial ecology issues, or land planning). For instance, designing a supporting system for novel and complementary visualization of data requires competences that are not available at hand (e.g. illustrate and show existing data in another format). Interoperability potential with existing tools is a key demand as existing data and tools are already implemented and used.

Third, circular economy benefits must be translated into tangible results. Industry managers must be able to identify and quantify synergies and define economic and environmental gains. In general, it is difficult to predict, which projects will be successfully implemented. Optimization of resource flows can be limited, and the existing tools and solutions may not cover all aspects of uncertainty and complexity. Consequently, scenarios are needed reflecting the complexity in management decisions to explore various resource management choices and handle multiple commodities (e.g. waters, energies, materials) and technologies at the same time. In addition, industry managers, in-

Table 2 Categories of sets of indicators for sustainable manufacturing (source: OECD, 2009).

Category	Description	Similar indicators or examples
Individual indicators	Measure single aspects individually	Core set of indicators Minimum set of indicators
Key performance Indicators (KPIs)	A limited number of indicators for measuring key aspects that are defined according to organisational goals	
Composite indicies	Synthesis of groups of individual indicators that is expressed by only a few indices	
Material flow analysis (MFA)	A quantitative measure of the flows of material and energy through a production process	Material balance Input-output analysis Material flow accounting Exergy; Material input per service (MIPS); Ecological rucksack
Environmnetal accounting	Calculate environment-related costs and benefits in a similar way to financial accounting system	Environmental management accounting Total cost assessment Cost-benefit analysis Material flow cost accounting
Eco-efficiency indicators	Ratio of environmental impacts to economic value created	Factor
Lifecycle assessment (LCA) indicators	Measure environmental impacts from all stages of production and consumption of a product/service	Ecological footprint Carbon footprint; Water footprint
Sustainability reporting indicators	A range of indicators for corporate non-financial performance to stakeholders	Global Reporting Initiative (GRI) Guidelines Carbon Disclosure Project
Socially responsible investment (SRI) indices	Indices set and used by the financial community to benchmark corporate sustainability performance	Dow Jones Sustainability Indexes FTSE4Good Index

dustrial park developers and local representatives must quantify the progress, which was achieved because of circular economy projects. Therefore, decision makers generally rely on previously defined key performance indicators (KPIs). These KPIs can be then used for their investment decision based on the complementarities, which they identify with the respective ecosystem. Table 2 provides an overview about possible categories of sets of indicators for sustainable manufacturing.

Fourth, circular economy promoters need to communicate results towards policy and decision-makers. The use of reporting tools and support documents allows the effective and efficient presentation of results towards different stakeholders.

2.5 Barriers to the implementation of circular economy

In projects, the implementation of circular economy principles encounter different types of barriers: finance, regulations and norms, technology, legal, organization and behavior (Ammoury, 2017; Bocken et al., 2017, Triguero et al., 2013, World Bank Group, 2017):

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Financial barriers: Sustainable investment is often perceived as non-profitable (e.g. insufficient financial returns or long term returns, high implementation costs) and hence, call for financial support that is not always provided by private banks. Industrial synergies are long-term installations and investments. Therefore, it is difficult to guarantee the system's resilience over time with new and changing conditions while predicting the financial implications, if one partner will leave, who previously secured a continuous resource supply.

Regulatory and normative barriers: Required authorization for industrial facilities can be difficult to obtain or may face the "Not in My Backyard" (NIMBY) phenomenon what may prevent the installation of new facilities and production plants. Moreover, lack of traceability or knowledge on the status of waste may prevent reuse of materials in new products or processes. Frequently, waste cannot be transported as a usual commodity and requires authorization to circulate.

Technological barriers: Technology may be a barrier to engage in a circular economy because of high switching costs when developing and deploying new technologies. Besides, closing material and resource loops is not always possible: much of the materials currently consumed are in dissipative uses, or others are commingled with other substances and thus difficult to recycle. The lack of existing technology or cost-efficient solutions, the demand for high quality of material, or energy flows can prevent the reuse of available waste or by-products. In addition, recycling solutions cannot always replace virgin materials. In some industries, recycled resources do not fulfil the material requirements in production (e.g. in high-end applications in industries such as medicine or automotive). In particular, recycled material is not used in high-performance materials because they might affect the constitution and stability of the surfaces of these materials and producers are afraid that they could be sued, if products will not fulfil the indicated product characteristics. Finally, necessary competences for synergy design or implementation may be also not available.

Legal barriers: Legal aspects can make the implementation of synergies difficult such as stakeholders' mutual dependency and competition. For instance, contracts must ensure a constant amount of resource supply, but sometimes waste is not produced at a constant level, or production sites of partners may be relocated.

Organizational and behavioral barriers: At a global level, political will and appropriate policies may miss and discourage the closing of resource and material loops. At the firm's level, missing collaboration and secrecy culture, and organizational complexity may lead to a lack of awareness and information sharing. This prevents trust, cooperation and involvement. Competition and the need to protect confidential data can hinder cooperation. Hence, individual strategies may not match together (long-term involvement vs. opportunistic behaviors). Eventually, some firms do not properly separate and collect waste what also impedes the recycling and reuse of materials. This also prevents the collection of data on existing waste streams. Furthermore, potential consumers are not always aware of available materials and resource flows.

The previous described barriers lead to uncaptured value at the end-of-life stage of a product. The main sources of value uncaptured at the end-of-life stage of a product for recycle, reuse and remanufacture are summarized in Table 3.

3 How a new generation of digital tools and services can support circular economy in industrial areas

Governments release public data opening the way to new opportunities (Blakemore et al., 2006; Jetzek et al., 2012). In doing so, business entities can add value to open data and generate revenue through re-using and disseminating them in a new form (Cerrillo-i-Martínez, 2012; Ubaldi, 2013). With renewed functionalities the use of data provide novel opportunities to make certain tasks easier in various industries, e.g.: data collected from satellite imaged for agriculture (Kamilaris et al., 2017), forecast and urban planning (Kitchin, 2014), and the launch of portals (Mahadevan, 2000). Geographical information systems (GIS) and the modelling of systems are typical functionalities of digital tools, whose quality can be improved by the use of real-time data. Digital tools and services are developed on both field and publicly available data.

In general, tools are used either to trigger circular economy initiatives or help to monitor

Table 3 Main sources of value uncaptured at end-of-life stage of a product (source: Yang et al., 2017).

Sources	Details
Recycle	▪ No or little recycling ▪ Lack of awareness and knowledge of recycling ▪ Valuable materials in discarded products ▪ Low-value disposal of recycled products ▪ No customer demand for recycling ▪ Lack of recycling guidance and methods
Reuse	▪ Idle, usable, re-purchased old products ▪ Insufficient use of usable old products ▪ Usable products discarded by customers ▪ Low-value disposal of usable products and components ▪ Poor customer acceptance of reuse of products ▪ Small market for used products
Remanufacture	▪ No or little remanufacturing ▪ Lack of awareness and knowledge of remanufacturing ▪ Need for low-cost remanufacturing technology ▪ No customer demand for remanufacturing ▪ Low acceptance by customer of remanufacture products ▪ Lack of remanufacturing guidance and methods

industrial synergies at an operational level. Some tools are more developed within one industry while others can embrace more sectors. For data visualization and IS identification, these digital tools and related methods usually rely on and combine data from generic databases, field data and publicly available data including governmental open data.

Different generations of tools were designed and launched as circular economy has developed over years, partly triggered by regulatory changes. They have been adapted to individual demand since the local context of users can differ strongly and especially among different countries with distinct regulation. In general, many of these tools were developed by universities or scholars and have evolved differently. The tools help to structure circular approaches and facilitate collaboration through partner and resource flow identification inlcuding information sharing. They also help to support design and land development processes through identification of suitable locations or land revenue optimization. In addition, they address different perspectives of sustainability ranging from facilitation tools (e.g. workshops), material flow analysis (MFA) to circular economy supporting methodologies developed by universities.

Existing tools and services can be sorted by the kind of circular economy or synergy approach they provide: empirical, deductive, or systematic approach (Harpet and Gully, 2013).

The empirical approach consists in following a trial and error process, but deals with a limited number of material and energy flows depending on circumstances and context. Forum and exchange workshops rely on such empirical approaches. A well-known digital tool, which follows the empirical approach, is NextGenPSD2 Implementation Support Programme (NISP ®). It has been developed in the UK and is diffused in other countries as well. The French environment agency Agency de l'Environnement et de la Maîtrise de l'Énergie (ADEME) has been using it in an extensive way.

The deductive approach helps to identify theoretical or technically feasible synergies based upon major resource or material flows related to one industry. They rely on (industrial) databases and identified flows. Umberto® is an example for tools based on the deductive approach.

The third approach is called systematic, which identifies and analyzes resource and material flows within a given system, from an industrial facility to all entities located in an area.

However, each approach considered individually suffers from specific drawbacks. Field approaches may identify synergies that are not feasible. Exchanges are rather casual than formally contracted. Besides, deductive approaches identify a limited number of flows and thus, synergies may lack reliable data and do not cover all resource and material flows. Hence, this is not very practicable for users. Finally, systematic approaches focus on a small number of flows, as they seek to optimize the lifecycle of materials or address one specific industry. Only few tools combine all three approaches and provide functionalities for interoperability among them.

4 Case studies: BE CIRCLE as an example of new digital tools and services for implementing circular economy

As an example for the new generation of digital tools that combine all three approaches, BE CIRCLE has been developed to lever barriers to circular economy. The service BE CIRCLE was developed during the course of an EU funded project by EIT Climate-KIC. It consists of services based upon a web platform to help industrial users implement circular economy approaches while using field data. In total, the service was tested by three experimenters. Two industrial parks tested BE CIRCLE, which were Espace INSPIRA in France and Industriepark Höchst with Provadis School of International Management and Technology in Germany and one port, which was the Port of Dunkirk in France. Each case study will be explained in detail below including a short description of the context of the project, the project and respective learnings and outcomes.

4.1 Case Study I: Industrial park INSPIRA

Context of the project: The Espace industriel responsable et multimodal INSPIRA (INSPIRA) is the second port site of the Rhone valley, located in the region Auvergne-Rhône-Alpes, 40 minutes south of Lyon. In the early 1970s the current INSPIRA site was mainly an agricultural area along the Rhône canal in the East of France. The industrial port has evolved since as a multi-modal hub thanks to various transport modes accessible on-site (waterway, railway and road). Moreover, spontaneous industrial synergies such as heat or hydrogen exchanges have developed between occupants and the neighboring chemistry platform (INSPIRA, 2019).

In 2009, the public entity Syndicat Mixte INSPIRA (SM INSPIRA) was created to organize, manage and further develop the industrial port. Very quickly after starting operations, SM INSPIRA recognized the opportunity to become one of the leading European eco-industrial parks. Its development strategy has henceforth consistently incorporated sustainability, of which industrial ecology is a key component. Today SM INSPIRA covers 330 ha, with 23 companies onsite of which 70% are members of a recently created association of enterprises on the site, and 160 ha remaining for new industrial manufacturers.

Description of the project: As a young entity with almost half of its land available, SM INSPIRA aims at developing a marketing strategy compliant with its principles of development and based on a circular economy approach.

The objective of the experimentation was to support the development of SM INSPIRA's marketing strategy focusing on two aspects: represent existing and potential synergies with the INSPIRA's industrial ecosystem, and identify the best locations for new plants that will facilitate industrial synergy creation with environmental and economic value.

In order to do so, information about INSPIRA's land management was integrated into the BE CIRCLE platform: utilities networks, telecom network, risk areas and easements. Along with SM INSPIRA, the port manager CNR was involved. Those two stakeholders have strong relationships with the industrial plants located on INSPIRA, hence they could echo their needs. Then the industrial plants were modelled to display the resource flows as inputs and outputs. SM INSPIRA and CNR modelled the industrial synergies already on-going between the facilities.

Subsequently, INSPIRA has been using the tool to promote its development strategy, communicate about its commitment regarding industrial ecology and facilitate decision process for new industrial entities.

Learnings and outcome of the project: In this experiment, BE CIRCLE helped to overcome different barriers. First, thanks to the use of generic data for the resource flows generation, the issue of industrial secrecy was resolved, allowing to triggering discussions about potential industrial symbiosis thanks to collaborative scenarios without having to share any specific data. When the future partners are getting ready to sign a Non-Disclosure Agreement (NDA) and share their own data to pursue feasibility studies, then the field data can be integrated into the BE CIRCLE scenarios. The use of an online platform helped to foster collaboration and participative mind-set among the stakeholders.

4.2 Case study II: Industriepark Höchst

Context of the project: The Industriepark Höchst is located in the state of Hesse in Germany and is operated by Infraserv Höchst. In total, more than 90 companies with around 22,000 employees are located at this industrial park, which has a size of over four square kilometers in the area of Frankfurt. Member companies of the industrial park are national and international research and manufacturing corporations, but also service providers (Infraserv, 2019).

Description of the project: The Industriepark is a very well developed industrial park and limited space is left for new settlements. Therefore, the case study aimed at the identification of new opportunities how to connect the industrial park with its external environment. For instance, on the one side, biogenic resources, which are available in the state of Hesse could be used by companies, which are located within the Industriepark Höchst. On the other side, by-products of companies of the Industriepark Höchst can be used outside of the industrial park (e.g. hydrogen as a by-product from the chlorine-alkali electrolysis for hydrogen refueling stations for fuel cell trains).

In a common case study, Provadis School of International Management and Technology and Infraserv Höchst tested the feasibility of exploiting regional open data to display biogenic resources within the Hessian region, which are available nearby the Industriepark Höchst. In general, biogenic resources have an organic source such as biogas or CO_2.

For the realization, of the case study, research was conducted to identify open data sources for regional biogenic resources supply within the state of Hesse. For the supplement of the case study, Infraserv Höchst provided field data for the perimeter of the industrial park plus buildings and transportation ways within the industrial park. For the beta test of the software, data for a pseudo exemplary resource flow network within the Industriepark Höchst were additionally provided.

The aim of the case study was to assess whether field and publicly available data regarding resource flows can be quickly and easily visualized within a large spatial area like a state and in an industrial park at the same time.

Learnings and outcome of the project: The case study combined different complementary approaches. BE CIRCLE could be tested with field and publicly available data for the visualization of resource flows. The integration of field and publicly available data was mainly automatically possible. However, some data must also be converted into another data format and/or manually integrated.

In this case study, BE CIRCLE served as a support tool, which could facilitate the preselection of spots for potential prospects or to identify new applications for (unused) by-products within or outside of the industrial park. This approach can foster discussions from a wider perspective on circular economy approaches and change the mind-set of different stakeholders towards new ideas on how to connect the industrial park with its external environment.

Indeed, companies are generally still reluctant to share data concerning their production to prevent that competitors might obtain insights into their cost structure or their competitive advantage. In addition, an industrial park operator may not possess plenty data regarding the resource inputs or outputs of its clients. Frequently, the industrial park operator only supplies or disposes some of the clients' resources. Hence, further data on the final and by -products of member companies of the industrial park may not be available, which could be then used to identify synergies. For a quick preselection of suitable locations, it may rather be more important to know which resources are generally available at a certain location or in its close or distant environment and visualize their presence and absence. Subsequently, experts can discuss the technical feasibility of closing resource loops or explore further alternatives.

4.3 Case study III: Port of Dunkirk

Context of the project: Dunkirk is the France's third-ranking port. It handles heavy bulk cargoes for numerous industrial installations. Besides, it is well positioned regarding cross-Channel Ro-Ro traffic to Great Britain. The port's territory covers 7,000 hectares and includes ten towns: Dunkirk, Saint-Pol-sur-Mer, Fort-Mardyck, Grande-Synthe, Mardyck, Loon-Plage, Gravelines, Craywick, Saint-Georges-sur-l'Aa and Bourbourg.

The Port has hosted industrial activities since mid-18th century, starting with the establishment of glasswork, faience pottery and cloth manufacture sites. From the 19th century onward major works were carried out in terms of facilities such as the construction of the railway to link Dunkirk to its hinterland, which allowed an important growth of the industrial activities. Today Dunkirk is the 7th port of the North Europe Range which extends from Le Havre to Hamburg (Dunkirk Port, 2019).

Description of the project: Industrial ecology has underpinned the development strategy of the port for several years and became a key component of its competitiveness. One of the main challenges today is about sustaining the existing synergies and developing new ones while certain facilities leave and others establish over time. To handle this, the port has been working on its territorial marketing strategy in order to identify which industrial sector to prospect that will best complement the local ecosystem in terms of complementary resource flows, bringing locally the resources needed by its neighbors and consuming their products and by-products.

A case study emerged with the departure of an old refinery in the eastern part of the port. The question of how to replace it was raised by Port of Dunkirk and Communauté Urbaine de Dunkerque (CUD), to which BE CIRCLE aimed to answer. The eastern part of the port was modelled on the BE CIRCLE platform using sectorial generic profiles for determining the input and output resource flows.

Based on the resources entering and leaving the industrial ecosystem, the "territorial marketing strategy" functionality was launched. The objective of such a functionality is to scan the BE CIRCLE internal database that encompasses the different industrial sectors with their resource profiles (what is produced, what is consumed) in order to identify the best match in terms of resource complementarity. A list of relevant sectors was delivered to the local players with their score of complementarity. Their relevance was discussed in a collaborative and participative approach. Then four sectors were selected in accordance with the port and local authority's preferences. The four related scenarios of establishment were developed and simulated in the platform integrating the potential symbioses with the neighbor facilities. Then, they were compared to each other in terms of environmental, social and economic performance thanks to seven indicators: the relative level of GHG emissions, the level of water circularity (linked to the volume of water reused locally), the part of renewables in the local energy mix, the number of symbioses created, the economic dynamism of the sector considered, the number of jobs created, and the impact on the surrounding road traffic, in terms of trucks flow density. These scenarios fostered the port's strategy regarding its prospection effort and the corresponding marketing arguments.

Learnings and outcome of the project: The case study showed that it was possible to integrate a whole database of industrial sectors profiles in BE CIRCLE in order to support the industrial park managers into their effort for building a consistent and eco-efficient ecosystem and create the favorable conditions for symbioses formation and growth.

5 What to consider while building your own circular economy case study with digital tools

IT tools require data for the visualization of resource flows and identification of synergies between different stakeholders. The following points below should be taken into account while using different data sources for the creation of a case study.

5.1 Data identification and integration

At the beginning, valuable data for the case study must be identified and integrated into the IT tool. In general, one of the main challenges is the access to appropriate and classified data plus their integration into digital tools. For IT tools, it is generally important that data can be compared to support management decision-making and to improve operational performance. In doing so, data aggregation and standardization is very important to collect and compare data. This will help to find innovative products and solutions. However, the indicators may differ from organization to organization depending on their context (OECD, 2009).

5.2 Data updates

Concerning the use of IT tools, one important aspect is the up-to-datedness of data to build valuable and reliable case studies. In general, a high interoperability with existing tools enables the possibility to integrate further data and additional tools can be used to enrich the case study. In particular, IT tools could be used at industrial parks, which are newly built up on a green field and data could be gathered from the beginning on within one data management system. This could reduce data compatibility and integration problems. In general, the aim should be the creation of intelligent data bases, which are connected and automatically update data in real-time or within a given time interval.

In contrast, if a network has a high degree of (technical) complexity, it might be very difficult to keep all data of the system up to date. Data management will be very time-consuming and thus, may not be practical and economically feasible. In this context, IT tools could primarily focus on the collection of data on a qualitative level. In this case, qualitative data should be used, which can be easily gathered and updated. In doing so, questions should start from open questions to more narrowed ones. For instance, the following questions could be used as selection criteria for the identification of novel opportunities for resource supply and use, or to find a suitable location for the establishment of new applications:

1. Is resource X available at a certain area?
2. If yes, which state of aggregation does it have (solid, liquid, gaseous)?
3. If resource X is available in gaseous state, at which pressure is it available (e.g. 1 bar, 3 bar, 7 bar)?
4. Which other resources are also available?

Finally, the insights and findings of such IT tools must provide more value than the time

Table 4 Checklist for data identification, integration and updates (source: own representation).

Data identification and integration	Data updates
▪ Who decides which data can be used and which cannot be used? ▪ How to identify "clean" and "good" data? ▪ How to use inconsistent data and how to "clean" them? ▪ Can all relevant data be gathered in the right format for data integration? ▪ Which and how can data be converted into the right format for data integration? ▪ Is it possible to connect data bases from different work tools of a plant or whole production plants of an industrial park? ▪ How is consistency in the integration of different databases ensured? ▪ How to characterize different industries, resources/commodities and their respective relevance for the case study?	▪ How is the up-to-datedness of data ensured? ▪ How can the data or databases be automatically integrated and updated? ▪ In which time intervals can data be updated? ▪ Who gives the permission to the system to automatically integrate and update data (employee or autonomous algorithm)?

invested to search, integrate and keep data up to date, or the fee, which must be paid for a service.

Table 4 provides a practical checklist regarding the data management for the application of digital tools in circular economy case studies.

5.3 Human facilitator

The development of digital services requires new competencies and new jobs emerge. Data managers and coordinators are required to facilitate the design and implementation of digital solutions in circular economy projects. Data managers or coordinators are professionals, who bridge customer relationship and circular economy project management by transforming data into valuable content (Lindmann et al., 2015). These novel roles can feed new businesses, which build upon new commercial services such as business intelligence services or exchange platforms.

6 Conclusion

In this article, barriers and challenges for the implementation of circular economy projects were described. Digital tools can help to overcome these barriers by using internal empirical and publicly available data to identify new possibilities of cooperation through the sharing of information and modelling of scenarios. In general, governments tend to release more and more public data bases. This provides new opportunities for the exploitation of publicly available data. Unknown opportunities could be identified without sharing own field data and having a high degree of internal restrictions at the beginning. For the application of digital tools, new roles are emerging. For instance, the role of a data integrator and coordinator becomes increasingly important, who has competences both in industry understanding and data management. New digital services like BE CIRCLE can help to connect stakeholders, change their mind-set and build ecosystems where firms can cooperate and exchange flows in a suitable way. Finally, the United Nations Sustainable Development Goals (UN SDGs) are especially a driver for industry's transition towards a more sustainable use of resources and provide incentives to engage in circular economy approaches (World Bank Group, 2017).

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During the course of the two-year project, a geo data-based web platform including further services was co-developed.

The platform allows defining scenarios for the identification of opportunities, which close resource loops and lead to positive impacts on competitiveness and environmental excellence of the local stakeholders.

BE CIRCLE gained recognition in 2018, where it was awarded the Jury's favorite Prize during the "Rencontres de l'Economie Circulaire" in Lyon. At international level, BE CIRCLE was nominee at the 2018 EIT Innovators Awards organized by the European Institute of Innovation & Technology (EIT), as a team from the EIT Communities that develops high-impact products and services for a sustainable future.

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References

Ammoury, N. (2017): *Les formes d'organisation utilisées pour développer des synergies d'écologie industrielle et territoriale: propositions de positionnement pour électricité de France (edf).*

Blakemore, M., Craglia, M. (2006): Access to public-sector information in Europe: Policy, rights and obligations, The Information Society, 22 (1), pp. 13-24.

Bocken, N. M. P., Short, S. W., Rana, P., Evans, S. (2014): A literature and practice review to develop sustainable business model archetypes, 65, Journal of Cleaner Production, pp. 42-56.

Bocken, N. M. P., Olivetti, E. A., Cullen, J. M., Potting, J., Lifset, R. (2017): Taking circularity to the net level: A Special Issue on the Circular

Economy, Journal of Industrial Ecology, 21 (3), pp. 476-482.

Boons, F., Chertow, M., Park, J., Spekkink, W., & Shi, H. (2017): Industrial Symbiosis Dynamics and the Problem of Equivalence: Proposal for a Comparative Framework, *Journal of Industrial Ecology*, **21** (4), pp. 938-952

Cerrillo-i-Martínez, A. (2012): Fundamental interests and open data for re-use, *International Journal of Law and Information Technology,* **20** (3), pp. 203-222.

Chertow, M. R. (2000): Industrial symbiosis: literature and taxonomy, *Annual review of energy and the environment*, **25** (1), pp. 313-337.

Chertow, M. R. (2007): "Uncovering" industrial symbiosis, *Journal of Industrial Ecology,* **11** (1), pp. 11-30.

Dumoulin, F., Wassenaar, T. (2014): Environment in industrial ecology, grasping a complex notion for enhancing industrial synergies at territorial scales, *Sustainability*, **6** (9), pp. 6267-6277.

Dunkirk Port (2019): *History of the port,* available at http://www.dunkerque-port.fr/en/dunkirk-port/history-dunkirk-port-origins.html, accessed 26 June 2019.

Ellen MacArthur Foundation, SUN, McKinsey Center for Business and Development (2015): *Growth Within: a circular economy vision for a competitive Europe*, pp. 1-97.

Geissdoerfer, M., Savaget, P., Bocken, N. M., Hultink, E. J. (2017): The Circular Economy–A new sustainability paradigm?, *Journal of cleaner production*, **143**, pp. 757-768.

Geng, Y., Doberstein, B. (2008): Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development', *The International Journal of Sustainable Development & World Ecology*, **15** (3), pp. 231-239.

Harpet, C., Gully, E. (2013*): Ecologie industrielle et territoriale: quels outils d'aide à la décision? De l'analyse des flux à l'approche intégrée, Déchets-Sciences et Techniques*.

Huber, G. W., Corma, A. (2007): Synergies between bio and oil refineries for the production of fuels from biomass, *Angewandte Chemie International Edition*, **46** (38), pp. 7184-7201.

Infraserv (2019): The Industriepark Höchst, available at https://www.industriepark-hoechst.com/en/stp/, accessed 29 June 2019.

Jetzek, T., Avital, M. and Bjørn-Andersen, N. (2012): The value of open government data: A strategic analysis framework, Pre-ICIS Workshop, Proceedings International Conference on Information Systems (ICIS) in Orlando, United States, pp. 1-12.

Joyce, A., Paquin, R. L. (2016): The triple layered business model canvas: A tool to design more sustainable business models, *Journal of Cleaner Production,* **135**, pp. 1474-1486.

Kamilaris, A., Kartakoullis, A., Prenafeta-Boldú, F. X. (2017): A review on the practice of big data analysis in agriculture*, Computers and Electronics in Agriculture*, **143,** pp. 23-37.

Kitchin, R. (2014): The real-time city? Big data and smart urbanism, *GeoJournal*, **79** (1), pp. 1-14.

Lieder, M., Rashid, A. (2016): Towards circular economy implementation: a comprehensive review in context of manufacturing industry, *Journal of cleaner production*, **115**, pp. 36-51.

Lindman, J., Kinnari, T, Rossi, M. (2015): Business Roles in the Emerging Open-Data Ecosystem, *IEEE Software*, **33** (5), pp. 54-59.

Lombardi, D. R., Laybourn, P. (2012): Redefining industrial symbiosis: Crossing academic–practitioner boundaries, *Journal of Industrial Ecology,* **16** (1), pp. 28-37.

Lowe, E. A. (1997). Creating by-product resource exchanges: strategies for eco-industrial parks, *Journal of cleaner production*, **5** (1-2), 57-65.

Mahadevan, B. (2000): Business models for Internet-based e-commerce: An anatomy, *California management review,* **42** (4), 55-69.

Mat, N. (2015): *Dynamiques de transition dans les territoires portuaires: apport de l'écologie industrielle et territoriale aux processus d'adaptation vers une société bas-carbone*, Doctoral dissertation, Saint-Etienne, France.

Meadows, D. H., Meadows, D. H., Randers, J., Behrens III, W. W. (1972): *The limits to growth: a report to the club of Rome*.

Moore, J. F. (1993): Predators and prey: a new ecology of competition, *Harvard business review*, **71** (3), pp. 75-86.

OECD (2009): *Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement - Synthesis Report.*

Porter, M., Van der Linde, C. (1995): Green and competitive: ending the stalemate, in: Wubben, E. F. M. (ed.), *The Dynamics of the eco-efficient economy: environmental regulation and competitive advantage*, Edward Elgar Publishing Limited, Glensanda House, Montpellier

Parade, Cheltenham, Glos GL50 1UA, UK, pp. 33-40.

Preston, F. (2012): A global redesign?: Shaping the circular economy, Chatham House, London, UK.

Rockstrom, J., Steffen, W. L., Noone, K., Persson, Å, Chapin, III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P, Foley, J. (2009): Planetary boundaries: exploring the safe operating space for humanity, *Ecology and Society,* **14** (2), article 32.

INSPIRA (2019): Un site stratégique, available at http://www.espace-inspira.fr/decouvrir/espace-industriel/un-site-strategique/, accessed 26 June 2019.

Teece, D. J. (2007): Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance, *Strategic management journal*, **28** (13), pp. 1319-1350.

Triguero, A., Moreno-Mondéjar, L., Davia, M. A. (2013): Drivers of different types of eco-innovation in European SMEs, *Ecological Economics*, **92**, pp. 25-33.

Ubaldi, B. (2013): *Open Government Data: Towards Empirical Analysis of Open Government Data Initiatives*, OECD Working Papers on Public Governance No. 22, pp. 1-60.

Van Berkel, R., Fujita, T., Hashimoto, S., Geng, Y. (2009): Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006, *Journal of Environmental Management*, **90** (3), pp. 1544-1556.

World Bank Group (2017): An international framework for Eco-Industrial Parks.

Yang, M., Evans, S., Vladimirova, D., Rana, P. (2017): Value uncaptured perspective for sustainable business model innovation, *Journal of Cleaner Production*, **140,** pp. 1794- 1804.

Zeng, H., Chen, X., Xiao, X., Zhou, Z. (2017): Institutional pressures, sustainable supply chain management, and circular economy capability: Field evidence from Chinese eco-industrial park firms, *Journal of cleaner production*, **155**, pp. 54-65.

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Practitioner's Section

Challenges and opportunities in the sustainability of communication devices – an operator perspective exemplified by Deutsche Telekom AG

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Considering that the communication devices (CD) segment only makes up just 7% of the yearly electrical and electronic equipment (EEE) waste, this means that there are no specific CD related sustainable measures, but just EEE generalized solutions. As such, this paper aims at exploring the critical factors for improving the sustainability as well as for the possible implementation of Circular Economy (CE) strategies for the CD segment along their entire supply chain. A wide range of factors pertaining to sustainability in the supply chain especially regarding the electrical and electronic equipment (EEE) market was gotten by means of an elaborate literature analysis. The factors are then compared to the present practices of the revenue leading telecommunications company in Europe, Deutsche Telekom AG (DTAG). From the literature review, we discovered a range of solutions a CD provider such as DTAG can use to improve the sustainability of its CD portfolio over the entire life cycle. These included ensuring that not only the communication company, but all the various suppliers follow sustainable practices such as Green Supply Chain Management or Closed Loop Supply Chain practices, and that they abide to the set of legislations and standardizations already in place for EEE such as REACH, RoHS, ISO 14004 and EPR. Good sustainable practice is also important, including the swapping of the present technologies for more sustainable ones and ensuring that SDGs are meet in the long run. Most of these methods and practices are already being implemented by the DTAG as part of their global strategy. In addition to an insight on the various concepts this industry should follow to ensure adequate implementation of CE, the study further provides suggestions as to strategies which could improve the sustainability of CDs.

1 Introduction

One of the authors is responsible for the quality and sustainability of DTAG's mobile device portfolio in Europe, therefore the study will focus on small Communication Devices (CDs).

1.1 Present state of the sustainability of communication devices

CDs are ubiquitous in our modern digital world and include smartphones, routers, media receivers, data sticks and many other subcategories. Normally, relatively small when compared to appliances but having very large annual production figures (e.g. 1.4 bill.

smartphones in 2018) (Reith et al. (2019)), the environmental impact of CDs is widely discussed in the public.

Cook and Jardim (2017) investigated the impact of the manufacture of electronic devices, particularly smartphones, onto the environment, with focus on the areas of energy consumption, resource consumption and hazardous chemicals. Albeit acknowledging that the major brands have made some progress in their voluntary sustainability commitments, the authors see massive environmental issues associated with electronic manufacturing. Root cause for several of those is the long and non-transparent supply chain. Other issues found by the authors are dirty energy, mounting electronic waste, little use of post-consumer material and substitution objectives for hazardous chemicals are not ambitious enough. Cook and Jardim (2017) cite another study according to which smartphones and other electronic devices are among the most resource intensive: for each 100g minerals required for a smartphone 34kg of rock must be mined. In addition, the contribution to the greenhouse gas emissions is seen critical as 80% of such emissions during a smartphone lifecycle is allotted to its production. Consequently, the authors request more responsibility for the supply chain (SC), design for sustainability and better strategies for end-of-life. For instance, their request for design for sustainability includes the elimination of hazardous chemicals and the use of recyclable material.

Dziamski et al. (2014) did a similar study nearly on the same device category already a few years earlier choosing climate protection, ecology and labor conditions as focus areas. The author came to the same conclusion as Cook and Jardim (2017) that the industry has significant sustainability issues, with both studies coinciding on several of these issues.

These two studies clearly suggest the need to make the CD business more sustainable. Leverages are to increase the utilization period and to introduce circular economy into the business. Revellio and Hansen (2017) looked into different strategies to implement circular economy into the smartphone industry. They conclude that there are functioning value creation architectures to achieve that. The important conclusion for the scope of this publication, though, is that smartphone design practices have a direct impact on the coordination efforts of the involved parties.

Stobbe et al. (2017) had a detailed look into smartphone design practices paying into the sustainability, in particular, durability, reparability and factorability for recycling. The authors identified different smartphone design practices and evaluated their advantages and disadvantages in the light of the above criteria. They have concluded that neither one is ideal with respect to sustainability. In particular, the use of glue in the smartphone assembly is seen as critical as it renders disassembly more difficult. It may even become dangerous if the Li-ion battery is glued in and its removal leads to a rupture of the pouch into which the Li-ion battery is sealed. This raises the question whether the use of glue is a good idea at all. However, there are many smartphone types with IP certification (dust and/or liquid proof) as well as a strong relevance of the aesthetic appearance as purchasing criteria for prospective customers. Both of which seems to render a substitution of gluing by other fastening methods as not realistic in the foreseeable future. This makes it necessary to look at the properties of the glues for smartphones and other CDs. Stobbe et al. (2017) also see that there are certain critical materials in smartphones in need of substitution by less critical alternatives. The authors have made a large number of proposals on how to design smartphones in a more sustainable way.

As of now, some major players in the smartphone industry already make use of some of these sustainable design practices, but there is certainly room to further implement more of such sustainable design practices. CDs are part of the consumer electronics which in general is relatively price-sensitive. This may help to explain why so far not more of such sustainable design practices are implemented. Other reasons may be a lack of suitable base materials that may either not be available at all or not available in the right amounts or at the right price point. Another reason is certainly the frequently non-transparent SC, as criticized by Cook and Jardim (2017), which in many cases may not allow component selection conscious of sustainability criteria. This may be compounded by difficulties to assess sustainability information on the side of some players in the electronic industry.

Looking at all those leverages to make the CD industry more sustainable would easily exceed the scope of this publication. There is agreement in the literature that harmful substances and a lack of sufficiently high amounts of post-consumer materials are relevant and significant issues. Both issues need to be solved mainly by improving the choice of materials. Hence, this publication will focus subsequently on the materials used for CDs. This is where Deutsche Telekom AG (DTAG) sees a benefit to initiate a dialogue and cooperation across the SC including the chemical industry which as a base material supplier has an important role in making CDs more sustainable.

1.2 The role of the supply chain

CDs are a product of a long supply chain which in a very high-level view is spanning from mines and crude oil wells, continuing with refineries and smelters, thence the refinery and smelter products are manufactured into base materials, these are turned into components, and finally these are assembled into completed CDs. This involves a lot of companies from several industries and therefore it is no surprise that Cook and Jardim (2017) bewail a non-transparent SC. In many of those SC stations the chemical industry plays an important role. Nevertheless, sustainability cannot be just considered from the perspective of the completed CD in isolation, but also needs to take all sustainability effects along the SC into account. This in turn implies that responsibility does not end at the company door but includes shared responsibilities with neighboring parties in the SC. In addition, there is another SC involved after usage of CDs which includes companies for collecting, disassembly and material recovery. In addition, the impacts onto that SC must be taken into the consideration.

Kim and Davis (2016) state in their study on Global SC Sustainability after an analysis of the SEC reports of the use of conflict material, the reports from over 1300 corporations showed that 80% of them admitted to being unable to determine the origin if the minerals, with only 1 % being able to certify themselves free of conflict materials. It is also mentioned that those less likely to declare their products conflict-free were firms, which are internationally diversified as well as the large ones with vastly dispersed SCs. Reason being that complexity reduces the transparency of the SC.

1.2.1 Sustainability x supply chain

Many companies have in recent decades adopted the shift towards environmental management as a key strategy to ensure a long -lasting organizational performance as well as retain advantages on global markets. This is a result of the creation of environmental standards as well as regulations by the governments, coupled with the customers' own self-awareness towards sustainability (Genovese et al., 2010). In order to achieve the highest success at the lowest possible cost, it is necessary to optimize along the entire SC (Handfield et al., 2002). The SC considers a product from the initial raw materials processing until delivery to customer, focusing here is a valuable option for wider adoption and development of sustainability. A study carried out by Linton et al. (2007) states that it is necessary to broaden the scope of the SC to consider and include issues and flows which go beyond the core of SC management, such as: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and end-of-life recovery processes (Linton et al., 2007). This view ensures that focus on environmental management and operations is shifted from just locally optimizing the environmental factors but also considering the entire SC during production, consumption, customer service and post-disposal disposition of products.

1.2.2 Green supply chain management

Going through literature there are quite a handful of studies addressing the issue of implementing sustainable supply chain management (SCM) practices in the electronics industry. Although the specifics of these studies do not directly address the CDs as of such, the findings can without doubt be considered for the CDs as highly relevant, seeing as they make up a large share of the consumer electronics' market. In the Table 1 (Kumar et al., 2017) below, we see that the CDs make up 7% of the yearly waste, which amounts to about 3 million tons.

With that in mind, the electronic device sector as well as the electrical industry on a whole have seen many changes to the SCM practices in the last decades. The most noticeable sustainable practice is that of implementing of green supply chain management (GSCM) prac-

Table 1 Varying WEEE Categories (source: Kumar et al., 2017).

Categories	Amount (million tons)
Temperature exchange equipment	7.0
Screens & monitors	6.3
Lamps	1.0
Large Equipment	11.8
Small equipment	12.8
Small IT and telecommunication equipment	3.0

tices relative to European Union directives (European Union, 2003). The aim of GSCM is to enable enterprises to achieve profit and market share objectives by reducing the environmental risk and impact (van Voek, 2013).

1.2.3 Internal environmental management

This is necessary for improving the enterprise's environmental performance (Melnyk et al. 2003). Of importance here is the support of those at the top of the hierarchy structure, the senior managers, as it is necessary and can be said to be a key driver to achieve a successful adoption and implementation of most innovations, technology, programs and activities (Hamel and Prahalad, 1989).

1.2.4 External GSCM practices

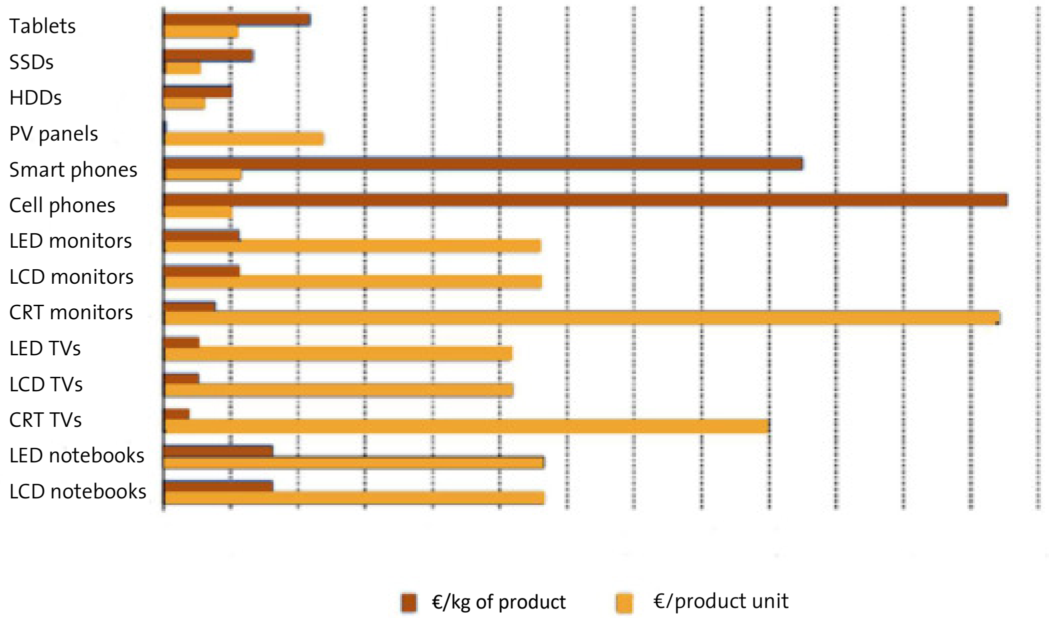
On the top of the list of external GSCM practices is the green purchasing. In order for a company to achieve maximum economic performance while at the same time minimizing the negative environmental effects, it needs to ensure that the SC is green by choosing green suppliers (Chou et al., 2016). Certain key factors need to be met for this to be adequately implemented such as providing design specification to the suppliers that includes environmental requirements for purchased items, cooperation with suppliers for environmental objectives, environmental audits for supplies' internal management, and suppliers' ISO 14001 certification (Chen et al., 2016). It is necessary that large companies exert pressure on their suppliers as well ensure that the practices of second tier suppliers are environmentally friendly (Zhu et al., 2008).

1.3 Legislations and Standardizations

Disposal of waste electrical and electronic equipment (WEEE) is a serious topic as about 30 -50 million tons of WEEE are deposited each year globally, with an estimation growth rate of 3-5 % (Afroz et al., 2013). This amounts to about 5,9 kg/inhabitant (Balde et al., 2017). Various substances exist within these wastes, which are critical, valuable and hazardous, and as such require a dedicated recycling process to avoid not just environmental and health issues, but also resource related issues (Cucchiella et al., 2015).

With this idea of the need to achieve sustainable development, the European Union (EU)'s WEEE directive came into force in August 2004, which requires that manufacturers and importers take back the used products from consumers and ensure that these are environmentally friendly recycled (Widmer et al., 2005). Coupled with this is another directive of interest to the field of electronic and electrical devices is the EU's restriction of hazardous substances (RoHS) which prohibits the use of regulated hazardous substances in the products viz. lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) (Wright and Elcock, 2006). The intent of both directives is the reduction of the problems associated with management of heavy metals and flame-retardants found in electrical and electronic equipment. The directives go a step forward to ensure that consumer awareness is increased by ensuring that producers label each piece of electrical or electronic equipment based on the appropriate disposal method before it hits the market. There also exists WEEE directive (2012/19/EU) aimed at the

Figure 1 Electronic Waste Streams for potential revenue (source: Cucchiella et al., 2015).



end of life management of wastes from electric and electronic equipment. Other EU compliance strategies exist which ensure that sustainable products are marketed in a transparent way. These include the energy-using products (EuP) regulation - with focus on the entire life cycle of products design, manufacture, use, and disposal, and the registration, evaluation, and authorization of chemicals (REACH) requirements – which requires that manufactures list all chemical ingredients contained, explain how they are used and include a toxicity assessment (European Commission, 2006).

Apart from the EU's set of compliances, there also exist standards aimed at ensuring the production of sustainable products. For example, the international organization for standardization's ISO 14001 standard has become the main reference in the field of corporate environmental management and with more than 300,000 organizations worldwide having adopted this standard it sees a yearly increase in adoption of about 10% (Boiral et al., 2018). Another instrument worth mentioning is that of the Organization for Economic Co-operation and Development (OECD), which entails that producers are given a significant responsibility, either financial and/or physical regarding post-consumer products, meaning that producers need to develop a sustainable reverse SC for the treatment or disposal of post-consumer products – named extended producer responsibility (EPR) (OECD, 2017).

1.4 The situation regarding materials

As mentioned before WEEE is rapidly growing and as such, it is necessary that this be adequately managed. With the expectation that the WEEE stream will gradually increase over the next years it is as such necessary to set up measures to deal with waste in this sector.

In their study on WEEE, Kumar et al. (2017) mention the three main benefits WEEE recycling brings about viz. economic, environmental and human health benefits.

On the level of economics, not only does material recovery offer better opportunities, it also offers a potential revenue stream (Figure 1) because the amount of scare resources mined will be reduced as well as job opportunities such as WEEE recyclers will emerge (Cucchiella et al, 2015; Heacock et al., 2016).

The environmental benefits here include reducing the amount of hazardous waste in the landfills as well as tackling issues like greenhouse gas emissions through energy savings (Cui and Forssberg, 2003). As for the human health benefits the damages related to the materials used in CDs is discussed in the subchapter below - "Materials for electronic components".

1.5 Technical polymers

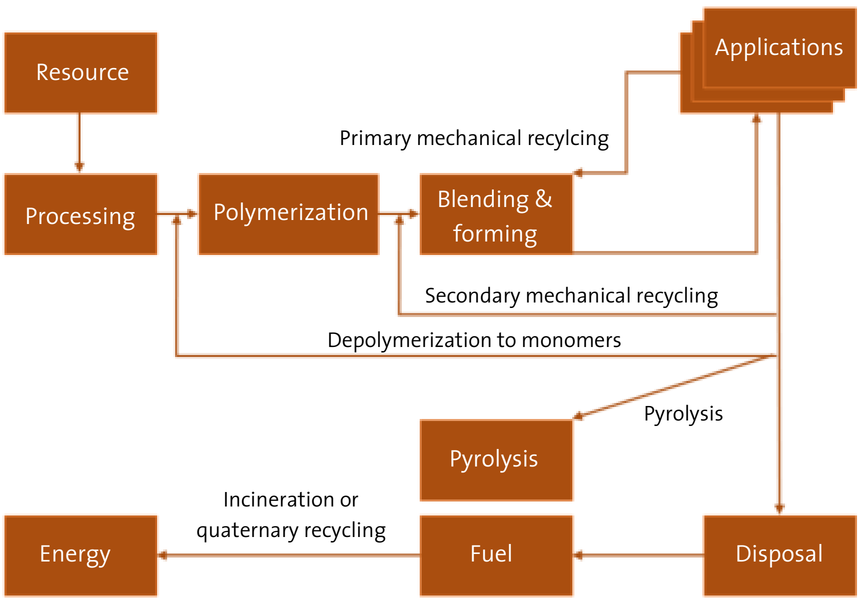
With the ever increasing and varying needs of end consumer products, the production of synthetic polymers is expected to triple by 2050 form over 311 million tons in 2014 (Hong and Chen, 2017). This leads to the problem of sustainability seeing as the vast majority of synthetic polymers are not designed for degradability and recyclability but for performance and durability (Jambeck et al., 2015). In their study on sustainability regarding the recycling of polymers, Hong and Chen (2017) mention three methods existing for the disposal of polymer waste: burying them in landfills, incineration for energy recovery, and mechanical recycling, with both landfilling and incineration lead to serious environmental issues with little or no material recovery. As for mechanical recycling, this method has been considered a temporary solution involving sorting, washing and drying postconsumer polymer products and thereafter these are melted into new polymer material (Ignatyev et al., 2014). Nonetheless, with this method there is the issue of moisture, residual catalyst and various contaminants, which exist in the polymer waste during the second melting process. Coupled with the issue that mechanical recycling is not adequate for colored polymer products due to various additional issues, this means that large majorities of polymers end up one way or the other in landfills or are incinerated.

There also exists the issue of the type of resources used in the polymer production. The production of the polymers is mainly petroleum -based and this brings about the problem of increased energy demand as well as the issue of recycling the enormous growth of disposed polymer wastes over the past few decades has brought (Moore, 2008). As such, there is need to replace these with more sustainable polymers from renewable resources.

1.6 Materials for electronic components

In Table 2 (Kumar et al., 2017) below, we see global sales data for various electronic devices. The life expectancies of these various devices as

Figure 2 Most common polymer recycling methods (source: Ignatyev, Thielemans, & Vander Beke, 2014)



seen in Table 3 (Ely, 2014; Kumar et al., 2017) goes to show that the most sold electronic devices are CDs. With the rapid change in the industry and technological advancements, the replacement period of CDs is very short, leading to older technologies eventually ending up in the waste streams.

Stobbe et al. (2017) clearly have pointed out that smartphones consist of a vast diversity of components and materials. Particularly trace elements are a problem. In a study from 2014, Beverley et al. (2014) analyzed a number of phones and came up with a list of 83 elements detected in some or all of them. These were: Be, B, Mg, Al, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Y, Nb, Pd, Ag, In, Sn, Sb, Te, Ba, Ta, W, Pt, Au, Tl, Pb, Bi, Pr, Nd, Sm, Eu, Gd, Tb, Dy, and Er. Present in this list are the Group IV and V trace elements vanadium, aluminum, gold and lead, which are all toxic to the human body and should be avoided landing in landfills (Prashanth et al., 2015).

In addition, an article on the effects of improper recycling of toxins present in cellphones

Table 2 Varying WEEE Categories (source: Kumar et al., 2017).

Items	Units (million)
Android phones	1675.45
iPhone 6	19.75
Total smartphone	12,444.89
Laptop & desktop	238.5
LCD TV	5.79
Plasma TV	0.63
CRT TV	0.55
Total TV	7.08
Printer	106,000
e-book reader	20.2
Home appliances	583
Electric ovens	0.733
Refrigerators	11.13
Automatic washers	9.68

Table 3 Lifespan Estimation for Electric and Electronic Equipment (source: Ely, 2014; Kumar et al. 2017).

Items	Units (million)
Flat panel TV	7.4
Digital camera	6.5
DVD player or recorder	6.0
Desktop computer	5.9
Blu-ray player	5.8
Video game console	5.7
Laptop/notebook	5.5
Tablet	5.1
Cellphones (not smartphones)	4.7
Smartphones	4.6

was published by the global recycling company e-Cycle. The presence of harmful elements like lead, mercury, arsenic, cadmium, chlorine and bromine is mentioned which can leak into groundwater and later on bio-accumulate in the food chain, thus causing detrimental damage to the soil, water supply, vegetation, animals and humans (e-Cycle, 2013). The effects on humans are wide as in that there is high possibility of damage to the reproductive, blood and nervous systems, with the mention of cancerous development as well. As such in order to ensure that the ever-increasing WEEE does not end up in landfill there is serious need for electronics recycling initiatives.

Another issue is that of the conflict materials. Over the past years, electronics companies have had a lot of pressure on them to ensure that their products are free as much as possible of conflict minerals especially those from the Democratic Republic of Congo (DRC). CDs being a consumer electronic have a high connection to the demand for the so-called conflict minerals from the DRC. Of the elements analyzed by Beverley et al., the typical conflict minerals are all present viz. tantalum, tin, gold and tungsten (Gosling and Prendergast, 2011).

1.7 Glues

Ease of disassembly has a direct impact on the commercial feasibility of repair and recycling, both are desirable from a sustainability viewpoint. The disassembly time drives cost that in case of recycling must be balanced against the revenue from the recovered materials and in case of repairs is one of the determining factors of the repair price and thus indirectly influences the end consumer acceptance for repairs. As Stobbe et al. (2017) have clearly stated, the use of gluing joints is a critical factor in the disassembly of smartphones. Even if the gluing joints can be separated by the application of heat, this adds to the time needed and complexity of a disassembly. It is becoming particularly bad if the gluing joints cannot even be separated by the application of heat. Although a better design for repair and recyclability for CDs is homework for the electronic industry and thus it needs to be done by itself, there is one thing the chemical industry can help with. As stated above, it is not likely to abolish gluing joints completely, but an expedient would be to devise innovative glues that facilitate disassembly. Potential ideas to achieve that will be discussed below.

2. Deutsche Telekom AG as an element of the supply chain

DTAG is heavily committed to the Sustainable Development Goals (SDGs) of the 2030 UN Agenda of Sustainable Development. As such corporate responsibility is an essential element of DTAG's business operations (see e.g. annual report (Deutsche Telekom, 2018)).

DTAG perceives itself as an important player in the SC. As shown above there is a clear need for the whole industry to introduce GSCM which is only possible by a close cooperation between the players in the SC. In pursuit of its corporate responsibility DTAG strives to intensify the cooperation in the SC to move towards GSCM.

CDs are heavily dependent on the network infrastructure. DTAG is at the interface and aims to have the CDs optimized for its network infrastructure to provide customers with the best possible network service experience. As part of that aspiration, DTAG issues technical specifications for CDs to ensure this best possible network experience. Since about 5 years requirements for sustainable design practices are part of that technical requirements set. The number of sustainability requirements as well as their ambition level has increased over the years. The intent is to guide the industry towards more implementation of sustainable design practices and thus to establish the ambitions for more GSCM with a tool.

3. Measures for more sustainability already taken by DTAG

Several researchers criticize harmful substances inside CDs, e.g., Cook and Jardim (2017), Dziamski (2014) and Stobbe et al.(2017). According to the opinion of the authors of this publication, although the existence of harmful substances in assembled CDs is by no means to be neglected, particularly plasticizers pose a problem as those may be released from polymer matrices, the key risk is in their uncontrolled release during mining, processing or component manufacture further up the SC. Likewise, the same risk may apply during recycling, particularly when not done professionally. Having so many mines, refineries, factories and workshops around the globe working with the associated minerals, components or complete CDs, it is practically impossible to control the risk at the root. Abstaining from harmful substance use in CDs has thus a multiplying effect as the environmental risks at each of the parties of the SC are also reduced as these numerous facilities do not need to process harmful substances then in the first place.

This is therefore an area requiring dedicated consideration and, foremost, action. In Europe, legislators have already taken action and have banned certain harmful substances from electrical and electronic devices. As already mentioned, the directives relevant for CDs is Reduction of Hazardous Substances (RoHS – 2011/65/EU), in Germany transposed into the Elektrostoff-Verordnung (ElektrostoffVO). RoHS limits polybrominated biphenyls (PBB), polybrominated diphenylethers (PBDE), lead (Pb), chromium of the oxidation state VI (Cr VI) and mercury (Hg) to 1000ppm in each component not further separable, while cadmium (Cd) is even limited to 100ppm. However, some selected exemptions to these limitations apply to cater for applications where there is not yet a substitute for these substances. For instance, 4 % Pb as a hardening element in copper alloys is exempted. This exemption is used in power plug pins to provide sufficient abrasion resistance for this application. Directive 2015/863 has added limitations for four phthalates (DEHP, BBP, DBP and DIBP) with a threshold of 1000ppm each, valid from July 22, 2019 onwards.

EN 62321 is the norm defining the chemical analytics to determine the essay of the substances limited by RoHS and to prove thus conformance to this directive. Various test labs offer chemical analysis following EN 62321 as a standard service. Each component is screened using X-ray fluorescence spectroscopy (XRF) followed by confirmation analysis by other methods if one of the elements limited by RoHS is found in the XRF spectra for certain components. Whenever DTAG is legally deemed the producer, an analysis report according to EN 62321 is required and formally approved by DTAG to ensure legal compliance.

In addition to RoHS also REACH (1907/2006) applies to CDs (European Commission, 2006). This is mainly related to Substances of Very High Concern (SVHCs). Chemical analysis reports for SVHCs are also evaluated for CDs where DTAG is legally deemed the producer. However, none of the SVHCs has been found in such CDs so far.

These directives are usually created in legislative procedures with the involvement of several stakeholders. In many cases this means a compromise in the sense of the least common denominator. Therefore, DTAG has commissioned a scientific study to investigate harmful substances typically found in CDs (Clemm and Deubzer, 2014). These harmful substances have been sorted according to whether already restricted by law and where a voluntary restriction would be desirable from an environmental viewpoint. Based on this, DTAG has put in 2015 into its technical requirements a voluntary limitation for phthalates, halogens, arsenic (As), antimony (Sb) and beryllium (Be). Phthalates have been limited by DTAG to 1000ppm in each non-separable component, where the whole substance class as such is limited. RoHS is following 5 years later, but only limits 4 phthalates out of a much larger number of this substance class still commonly in use. In relation to halogens DTAG follows the norm IEC 61249-2-21 for halogen-free: maximum 900ppm chlorine, maximum 900ppm bromine or 1500ppm of both halogens combined. This implicitly prevents the use of PVC or chlorinated respectively brominated flame retardants. As, Sb and Be have been limited to 100ppm each analogous to the limitation of Cd by RoHS. Only gallium arsenide has been excluded as there is presently no adequate substitution for this semiconductor material. Subsequent discussion with the SC has effectuated that several major players in the CD industry widely follow DTAG's voluntary substance limitations.

The analytical proof for the voluntary harmful substance limitations of DTAG is so designed as to be executed in synergy with the evidence for RoHS conformance in analogy to EN 62321.

Substances for CDs are not selected for the sake of itself. Besides cost and availability considerations, substances are chosen as a best material fit for a certain set of functional requirements. DTAG's voluntary substance limitations do not pose hardware designers with unsurmountable hardware design challenges. In a follow-on study Clemm et al. (2015) have been able to demonstrate that for each of the substances limited voluntarily by DTAG, substitutes are readily available on the market. This in turn demonstrates that at least in these cases substance selection for CDs has alternatives for substitutes. The challenge is rather to have some CD suppliers considering such alternatives, but in these cases, there are no unsurmountable physical obstacles.

DTAG also strives to foster circular economy as part of its sustainability policies. As such DTAG requires the use of post-consumer materials in devices and device packaging. While this works quite well with post-consumer cellulose fiber for packaging materials, the use of post-consumer plastics still has some challenges. Post-consumer plastics are shredded and added to a certain percentage to plastic pellets for the mold injection of new plastic parts. This has the disadvantage that the additives optimized for the previous use are dragged into the new application for which they are not intentionally designed. For instance, it is very difficult to obtain bright colors for plastic housings when using high percentages of post-consumer plastic. In consequence, DTAG's desire to use higher percentages of post-consumer plastics meets technical limitations and requires a compromise with other DTAG requirements. The chemical industry is seen here as the solution provider to solve this dilemma by developing innovative plastic waste processing procedures and novel materials that will not require such compromises. The authors of this publication see that as the prerequisite to request 100% post-consumer plastics from the CD industry. In the following sections we will look into trends and propose some development routes how this can be achieved.

4. Upcoming measures by DTAG

Legal and DTAG's voluntary harmful substance limitations, as described above, do not cover all harmful substances that may be present in or used for the manufacture of CDs. The UNECE globally harmonized system of classification and labelling of chemicals (GHS) defines in part 3 (H300-373) various health hazards and in part 4 (H400-433) various environmental hazards. The ideal from a sustainability viewpoint of course would be that none of the substances classified by any such hazard statements is used in or for CDs. DTAG has recently included this into its technical requirements.

Though DTAG is fully aware of the fact that this is quite a challenging requirement for base material developers, it is nonetheless intended to send a signal into the industry that sustainability needs to become a more significant target for base material development. Thus, in a realistic expectation, it will take some lead-time before this requirement will be completely fulfilled, but it is important that the conscious consideration of hazard statements of candidate constituents becomes a routine criterion for the formulation of materials. CD components must be developed and selected following a sustainability risk minimization principle.

Another route to approach the fulfillment of this requirement is to reduce the amount and variety of material components to the inevitable minimum as any additional component increases the risk of having a substance in with a relevant hazard statement. In addition, a large variety of components also renders material recovery as part of recycling more difficult, particularly if certain substances are present inside CDs in just very small amounts. For plastic materials, the at least theoretical ideal would be a composition of only the polymer without additives. The vision would be to modify the polymer structure itself to get the material properties as close as possible to the desired ones. Parameters could be the average chain length, degree of cross-linking or modifications to the monomer molecules. This changes the polymer synthesis strategy from large batches of the base polymer, which needs to be customized by additives, towards more, but smaller batches of individual polymers, which are already customized by their structure and contain smaller amounts of additives or none at all. This strategy would also have the advantage that the additives do not pose such a problem for applications using post-consumer material or in waste plastic processing. Reducing the material components diversity inside CDs thus serves two important sustainability targets: ease of recycling and harmful substance avoidance.

The challenges with the presently available post-consumer plastic have already been discussed above. Notwithstanding this, DTAG sticks to the requirement of using the highest percentage of post-consumer material that is technically still feasible, which is ideally 100%. DTAG sees a resolution in innovative processing procedures for waste plastic that allow to yield post-consumer plastic that is chemically identical with plastic obtained from fossil sources.

Potential ways to do that will be discussed in the next section.

5. Resulting requirements for more sustainable materials

5.1 Sustainability as a differentiator in a highly competitive industry

With the awareness that logistics and SC managers need to ensure the balance between cost reduction and innovation while at the same time maintaining good ecological performance, GSCM as such has become an important competitive approach for organizations, with multinational enterprises setting up global networks of suppliers to take advantage of country-industry specific characteristics for building on competitive requirements (Pagell and Krumwiede, 2004; Narasimhan and Carter, 1998). Although the benefits of GSCM and CLSC practices have seen increasing importance, there also exist the environmental regulations such as the EPR, WEEE Directives and RoHS, which have pushed the market's competitive standpoint towards a more sustainable one. Christmann and Taylor (2001) mention that sustainable SCM practices such as GSCM and closed supply chain loop (CLSC) have been implemented by Chinese enterprises as a means to establish foreign relationships and assure foreign market positioning. The analysis of their survey data showed that firms in China with multinational ownership, multinational customers, and exports to developed countries increase their self-regulation of environmental performance.

5.2 Concepts for a Circular Economy for technical polymers

One problem of the present polymer economics is the for polymers required carbon is still coming mostly from fossil sources. From a sustainability perspective, it would be desirable to circulate the carbon that is already in the atmosphere. As already mentioned, the main strategies presently to deal with waste polymers are landfilling, incineration or mechanical recycling. The key problem in case of mechanical recycling is the presence of residues from the first use during the second melting process (Hong and Chen, 2017). These authors deemed this approach therefore as a temporary solution. The authors of this study believe that the presence of residues from the first use or recycling process significantly limits the applicability as post-consumer material. This in turn leaves presently few alternatives to reuse waste polymers aside landfilling or incineration. Thus, in order to create demand for post-consumer plastic other recycling strategies need to be found that remove the limitations imposed by the presence of residues from the first use. Such a demand would be a promising strategy to remove substantial volumes of waste polymers from landfilling and incineration channels. Therefore, the following subsections discuss alternative strategies on how to improve the Circular Economy scope for plastics:

- Chemical decomposition of plastic waste to obtain monomers
- Plastic made from renewable sources which is also biodegradable (mimicking the seasonal leafage cycle)
- CO_2 as a reagent for the synthesis of polymers and common monomers

5.2.1 Chemical decomposition of waste plastic to obtain monomers

The most abundant technical polymers used in CDs are polycarbonates (PC), acrylonitrile-butadiene-styrene copolymer (ABS) or a blend of both. Typically, housing and structural parts consist of these polymers which are thus by weight the most significant polymers used in CDs. Other uses of polymers are the carrier materials of printed circuit boards, which in most cases consist of glass-reinforced resins, and displays where in some cases polymethylmethacrylate (PMMA) substitutes PC as the material for transparent foils. There are other plastic parts, such as connectors and flexible cables to connect components inside CDs, but which are in terms of the contribution to the total polymer weight just minor.

To ensure that the recycling of these polymers is sustainable it is necessary to have a circular economy approach. Of the various solutions being researched, chemical recycling seems to be the one with the most progress concerning the environmental and technical benefits (Hong and Chen, 2017). With regards to PC, they have high valuation as they belong to a class of engineering plastics which exhibit excellent mechanical and/or thermal properties, with a global market compound growth rate of 8.2% expected to reach $91.8 billion by 2020 from $57.2 billion in 2014 (Smith, 2019). Sad enough the unique resin structure means that PCs cannot be mechanically recycled and end up mostly in landfills as waste (Antonakou and Achilias, 2013). To remedy this situation, Jones et al. (2016)mention that waste PCs can be repurposed into value-added poly(aryl ether sulfone) known as PSU materials, which as a type of technical polymer can be used for reverse osmosis and water purification membranes, as well as high-temperature applications (Jones et al., 2016). It is mentioned in the same study that PC is chemically decomposed under influence of an alkali with CO_2 being lost as a by-product, and the product bisphenolate then in the presence of a carbonate salt undergoes a polycondensation reaction at 190 °C for 18h to produce the PSU. This method as such ensures a PC cradle-to-cradle life cycle.

On the other hand, the PMMA through pyrolysis at temperatures of 450 °C can be effectively depolymerized to more than 98% of the monomer (Kaminsky et al., 2004). Nevertheless, the existence of colorants and other contaminants might lead to the production of non-wanted/environmentally dangerous by-products. Another solution to the issue of recycling for both ABS and PC is that of combining both scraps (Larsson and Bertilsson, 1995). An ABS or ABS/PC blend enables certain mechanical properties to be recovered, especially toughness lost during usage either artificially or naturally. However, this works only as second-life solution seeing as the gotten product will need recycling in the end. A means to remedy these issues is the use of bio-based polymers as discussed below.

5.2.2 Bio-based polymers as sustainable substitutes

Nature has already established a circular economy for leafage. In autumn trees and bushes drop their leafage which in turn is decomposed by microorganisms to CO_2 and water. In spring, the whole process is turned around and leafage is generated by photosynthesis from CO_2 and water. In analogy to that, the circular economy for polymers can be closed by the synthesis of polymers from renewable sources (i. e., plant material) and by also making those polymers biodegradable. To avoid potential ethical conflicts, only those renewable sources may be used that are not in competition with foodstuff.

Agarwal et al. (2012) analyze in their 2012 study the plant-based monomer α–methylene-γ–butyrolactone (MBL) or tulipalin A (Agarwal et al., 2012), they state that bio-based polymers can be made from monomers that are either bio-based (derived from renewable sources) or naturally gotten from plants. The monomers can be polymerized through various techniques like condensation polymerization, vinyl polymerization, ring-opening polymerization and metathesis polymerization with the use of renewable sources such as plant oils, polysaccharides and sugars. There is also the possibility to directly produced vinyl polymers from plant-based monomers. One of these is MBL, which as an alternative to petroleum-based methyl methacrylate (MMA), can be found naturally in tulips or produced from biomass feedstocks. It can be used as a natural gotten vinyl monomer for the synthesis of biopolymers, due to its exo-methylene double bond.

5.2.3 CO_2 as a reagent for the synthesis of polymers and common monomers

Although CO_2 is an inert molecule it still can be converted with energy input and suitable catalysts into polymers, monomers or monomer precursors. There are numerous publications dealing with the subject. Here only a brief selection is discussed which has a potential relation to the circular economy for polymers.

Out of those only one is cited here to illustrate the principle: Wasmus et al. (1990) have investigated the electroreduction of CO2 at copper electrodes. Methane and ethene have been found as reaction products. The authors have been able to identify conditions where more ethene than methane is produced. Ethene in turn is used directly as a monomer or precursor of monomers in various synthesis routes for polymers.

These electrochemical approaches will show their full potential for sustainability when the required electrical energy is generated from renewable sources, such as photovoltaic or wind energy.

Another alternative to input the energy required to reduce CO_2 is the utilization of light in photochemical approaches. One of them is the photo-catalytic conversion of CO_2 to hydrocarbons and renewable fuels such as methane and ethylene (Steinlechner and Junge, 2018; Royer et al., 2018). Ethylene in its oxide form can be readily used as raw material alongside CO_2 and bisphenol for PC production in a phosgene-free process (Fukuoka et al., 2003). The direct use of light energy enables the usage of intermediary energy to be avoided as in potential electrochemical approaches.

Both approaches are still in the state of fundamental research, but show the basic feasibility of this strategy for the Circular Economy of polymers. Before becoming suitable for technical application, various problems need to be overcome, such as low conversion efficiency, high overvoltage in case of electrochemical approaches and long-term catalyst stability. Therefore, this is certainly not a short- or even mid-term solution but deserves further research as a long-term enhancement of the options to establish a circular economy for polymers.

There are also approaches to use CO_2 directly for polymer synthesis. For instance, there are already technical processes for the synthesis of PC through copolymerization of CO_2 with epoxides (Klaus et al., 2011). This idea has been around for more than 40 years now, first provided by Inoue et al. who through this copolymerization with a heterogeneous catalyst produced from diethyl zinc and equivalent water, opened up the a new filed to CO_2-based polymers (Inoue et al., 1969). Following this, a team again composed of Inoue in 1983 combined ZnET2, water, CO_2 and PO to produce a small quantity of polymeric material in the first single -site catalyst process for CO_2/epoxide copolymerization (Aida and Inoue, 1983). Lu et al. (2012) analyzed the development of highly Co (III)-based catalysts for the PC selective production from alternating copolymerization of CO_2 epoxides. Reason for this as stated in their research is that, although this method of CO_2 usage could yield a very valuable polymeric material – biodegradable PC, it often generates unwanted by-products such as polyether and ether linkages, which disperse within the PC chains. Because of this, the catalyst choice is seen as critical factor for the selective creation of the expected product. This selective transformation of CO_2 into biodegradable PCs as such sets the stage for potential large-scale sustainable utilization of CO_2 in chemical synthesis.

5.3 Reducing harmful substances and substance diversity in communication devices

The substance diversity in CDs has mainly two consequences for sustainability:

- The risk that one or more of these substances have harmful properties grows with their number.
- Material recovery during recycling is impeded.

Consequently, reducing harmful substances and substance diversity in CDs shows a congruency to some extent. After having reduced substances to an inevitable minimum, the residual task is to ensure that the remaining essential substances are selected in a way as to have no harmful properties or, at least, their harmfulness corresponds to the absolute minimum that is technically feasible.

There is also a commercial risk in so far as some of the materials are scarce and may get into short supply which drives cost. This is particularly valid for those substances whose natural mineral deposits are concentrated in a few countries or even just one. Any political problem in or with those countries may have an immediate impact on availability.

These constitute good reasons to devise strategies to reduce the substance diversity in CDs. Based on recent requirements from DTAG, strategies to reduce substance diversity in polymers have already been discussed above. The question is which strategies may apply for the other components that go into CDs. For metals it seems straightforward: copper is probably irreplaceable due to its good electronic conductivity. For the other metal parts, the authors can very well envision a unitary metal or alloy that combines the required physical properties of the various parts in an at least reasonable compromise. This would have significant benefits for sustainability:

- The number of mines in the SC and their potential negative impact would be reduced, as there are a fewer minerals required as the starting points of the SC.
- Sorting during recycling would be reduced as there are only two different types of metal (copper and the unitary metal).

- Material recovery would be facilitated as having a unitary metal means that its amount per CD is typically larger as if the metal portion of a CD is shared by several metals.

Sorting batteries from recycled CDs is already relatively straightforward as there is across CDs a de facto unitary solution in the form of Li-ion batteries with only a few exceptions.

Reducing the substance diversity in electrical parts, such as ICs, resistors, sensors and capacitors, is comparatively more complex. Even the same kind of electrical part may have sub-types which all are distinguished by their chemical composition. In a first step it would be desirable to reduce the number of different sub-types for each electrical component inside CDs which would eliminate already some of the substance diversity. In another step it would be desirable to develop a multi-purpose material that is good enough to be used across a range of electronic components by having properties broad enough to fit the different physical and chemical requirements of the application in different electrical parts. By way of example electrolytic capacitors are available made from oxides of aluminum, niobium or tantalum. For the authors it seems to be feasible to agree for that purpose on one of the materials and abolish the other two, or for that matter, develop a "super"-material that is able to replace all three of those.

5.4 What can the chemical industry do to make CDs more repair and recycling friendly

As was discussed above the frequent use of gluing joints in CDs is hampering repair and recycling. The key to this problem is the requirement that the glue needs to keep parts firmly fixed during use. That benefit turns into the opposite when a low connection force is desired, that is disassembly for repair or recycling. This dilemma could be resolved by designing a glue that fulfils both: It will hold the parts firmly during use but stops doing so when required. This concept requires a type of adhesion that can be annulled by any form of a suitable trigger. This implies some form of control of the molecular forces at the interface between glue and bonded part by a suitable physical or chemical mechanism. The authors are aware that this is quite a challenging development task, which probably even requires some better fundamental understanding of molecular forces at the interface.

6. Conclusion: suggested strategies for more sustainable materials

There are political, social and economic drivers for more sustainability expected to become more significant in the foreseeable future. Parallel to that, sustainability will gain a growing impact on corporate operating costs by GHG taxes, emission certificate trade or other means. The CD industry will need to find an answer to that.

Base materials play an important role for CDs. Although there are several promising approaches in the industry, the authors see a differentiation and growth potential for base materials that help the CD industry to become more sustainable. This in turn requires some redirection of product development strategies in the chemical industry as the supplier of base materials for the CD industry. Differentiation by innovation and sustainability can be merged.

Innovation is not only about inventing new products; likewise, existing products can be done in innovative processes that reduce the GHG emissions and other environmental impacts during their production. The differentiation is then by helping the following parties in the SC to also reduce their footprint. Even higher prices may still be accommodated by being balanced against lower taxes or costs for GHG emissions certificates. Novel procedures for waste plastic processing for better material reuse, innovative polymer formulations to reduce additives and harmful ingredients or the use of biopolymers, all have the potential to become such differentiating products for the chemical industry.

"Super"-materials that can be used in several functions in electronic components, that today require the use of several different ones, could be another strategic development approach to leverage the smartness of the materials also into more sustainability. Even though demanding, intelligent glues, that stick when they should, but do not stick when they should not may be also a strategic development approach. Not only in the CD industry have gluing joints played an increasingly important role, but also in other industries.

All those approaches still require additional development efforts in labs, in pilot plants and large-scale manufacturing. This is a chance for those industrial sites that have the infrastructure and experience to cope with it. In fulfilment of its own responsibility, DTAG sees its role in mediating between the different players in the SC and thus bringing sustainability into CDs. At the end, sustainability is a team effort in the SC.

As a limitation, this study lacks a sufficient data framework for sampling and this means that certain measures especially concerning recyclability are missing. As a proposition for further works and to ensure that an in-depth analysis can be conducted, more information relevant to CE for CDs such as ecological carbon footprint data and fair labor needs to be gotten.

References

Afroz, R., Masud, M. M., Akhtar, R., & Duasa, J. B. (2013): Survey and analysis of public knowledge, awareness and willingness to pay in Kuala Lumpur, Malaysia-a case study on household WEEE management, *Journal of Cleaner Production*, **52**, 185–193.

Agarwal, S., Jin, Q., & Maji, S. (2012): Novel amphiphilic, biodegradable, biocompatible, cross-linkable copolymers: Synthesis, characterization and drug delivery applications, *Polymer Chemistry*, **3**(10), 2785–2793.

Aida, T., & Inoue, S. (1983): Activation of Carbon Dioxide with Aluminum Porphyrin and Reaction with Epoxide, Studies on (Tetraphenylporphinato)aluminum Alkoxide Having a Long Oxyalkylene Chain as the Alkoxide Group. *Journal of the American Chemical Society,* **105**(5), 1304–1309,.

Antonakou, E. V., & Achilias, D. S. (2013): Recent advances in polycarbonate recycling: A review of degradation methods and their mechanisms, *Waste and Biomass Valorization,* **4**(1), 9–21.

Balde, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017): *The global e-waste monitor 2017,* In United Nations University.

Beverley, C., Romanov, A., Romanova, I., & Turbini, L. J. (2014): Elemental Compositions of Over 80 Cell Phones. *Journal of Electronic Materials,* **43**(11), 4199–4213.

Boiral, O., Guillaumie, L., Valery, C., & Tene, T. (2018): Adoption and Outcomes of ISO 14001: A Systematic Review, **20,** 411–432.

Chen, H. M. W., Chou, S.-Y., Luu, Q. D., & Yu, T. H.-K. (2016): A Fuzzy MCDM Approach for Green Supplier Selection from the Economic and Environmental Aspects, *Mathematical Problems in Engineering,* 2016.

Christmann, P., & Taylor, G. (2001): Globalization and the Environment: Determinants of Firm Self-Regulation in China. *Journal of International Business Studies,* **32**(3).

Clemm, C., & Deubzer, O. (2014): *Guideline to legislative and voluntary substance bans in the ICT sector*, Berlin, Darmstadt.

Clemm, C., & et al. (2015): Substitution of critical substances in ICT devices, Berlin, Darmstadt.

Cook, G. (Greenpeace), & Jardim, E. (Greenpeace). (2017): *Guide to Greener Electronics | Greenpeace International,* Greenpeace Reports, available at http://www.theguardian.com/sustainable-business/2015/apr/30/dell-makes-computer-industrys-first-recycled-computer, accessed 2 April 2019.

Cucchiella, F., D'Adamo, I., Lenny Koh, S. C., & Rosa, P. (2015): Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, 51, 263–272.

Cui, J., & Forssberg, E. (2003): Mechanical recycling of waste electric and electronic equipment: A review, *Journal of Hazardous Materials*, **99**(3), 243–263.

Deutsche Telekom. (2018): *Annual Report 2018,* available at www.telekom.com/annualreport, accessed 2 April 2019.

Dziamski, M., Niels, O., Thöne, R., & van Woersem, Y. (2014): *Sustainable Electronics Report 2014,* Rank a Brand e.V, 1–19, available at http://www.rankabrand.org/static/electronics-green-fair-ranking-report-2014.pdf, accessed 2 April 2019.

e-Cycle. (2013): *Cell Phone Toxins and the Harmful Effects on the Human Body when Recycled Improperly*, available at https://www.e-cycle.com/cell-phone-toxins-and-the-harmful-effects-on-the-human-body-when-recycled-improperly/, accessed 2 April 2019.

Ely, C. (2014): The Life Expectancy of Electronics, available at http://www.cta.tech/Blog/Articles/2014/September/The-Life-Expectancy-of-Electronics, accessed 2 April 2019.

European Commission (2006): Regulation (EC) 1907/2006 of the European Parliament and of the Council of 18 December 2006 - REACH, *Official Journal of the European Union*, available at https://doi.org/http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?, accessed 2 April 2019.

European Union. (2003): Directive 2002/96/EC: EU-Directive 2002/96/EC: Waste Electrical and Electronic Equipment (WEEE*). Off. J. Eur. Union,* **46**([L37]), 24–38.

Fukuoka, S., Kawamura, M., Komiya, K., Tojo, M., Hachiya, H., Hasegawa, K., Konno, S. (2003): A novel non-phosgene polycarbonate production process using by-product CO 2 as starting material, *Green Chemistry,* **5**(5).

Genovese, A., Koh, S. C. L., Bruno, G., & Bruno, P. (2010): Green supplier selection: A literature review and a critical perspective*, Supply Chain Management & Information Systems* (SCMIS), 1–6.

Gosling, R., & Prendergast, J. (2011): Congo's Conflict Minerals: The Next Blood Diamonds, available at https://www.huffingtonpost. com/ryan-gosling/congos-conflict-minerals-_b_854023.html?gu-counter=1&guce_referrer_us=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_cs=yrmWccn1yt4L4oIFujqfmQ, accessed 2 April 2019.

Hamel, G., & Prahalad, C. K. (1989): Strategic intent, *Harvard Business Review,* **67**, 63–76.

Handfield, R., Walton, S. V, Sroufe, R., & Melnyk, S. A. (2002): Applying environmental criteria to supplier assessment.pdf, *European Journal of Operational Research,* 141, 70–87.

Heacock, M., Kelly, C. B., Asante, K. A., Birnbaum, L. S., Bergman, Å. L., Bruné, M. N., Suk, W. A. (2016): E-waste and harm to vulnerable populations: A growing global problem, *Environmental Health Perspectives*, **124**(5), 550–555.

Hoek, R. I. van. (2013): From reversed logistics to green supply chains*., Supply Chain Managment: An International Journal.*

Hong, M., & Chen, E. Y. X. (2017): Chemically recyclable polymers: A circular economy approach to sustainability, *Green Chemistry,* **19** (16), 3692–3706.

Ignatyev, I. A., Thielemans, W., & Vander Beke, B. (2014): Recycling of polymers: A review. *ChemSusChem,* **7**(6), 1579–1593.

Inoue, S., Koinuma, H., & Tsuruta, T. (1969): Copolymerization of carbon dioxide and epoxide, *Journal of Polymer Science*, **7**(4), 287–293.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Law, K. L. (2015): the Ocean, *Marine Pollution*, **347**(6223), 768–771.

Jones, G. O., Yuen, A., Wojtecki, R. J., Hedrick, J. L., & García, J. M. (2016): Computational and experimental investigations of one-step conversion of poly(carbonate)s into value-added poly(aryl ether sulfone)s, *Proceedings of the National Academy of Sciences,* **113**(28), 7722–7726.

Kaminsky, W., Predel, M., & Sadiki, A. (2004), Feedstock recycling of polymers by pyrolysis in a fluidised bed, Polymer Degradation and Stability, **85**(3 SPEC. ISS.), 1045–1050.

Kim, Y. H., & Davis, G. F. (2016): Challenges for Global Supply Chain Sustainability: Evidence from Conflict Minerals Reports University of Michigan University of Michigan, *Academy of Management Journal.*

Klaus, S., Lehenmeier, M. W., Anderson, C. E., & Rieger, B. (2011): Recent advances in CO 2 / epoxide copolymerization — New strategies and cooperative mechanisms, *Coordination Chemistry Reviews,* **255**(13–14), 1460–1479.

Kumar, A., Holuszko, M., Crocce, D., & Espinosa, R. (2017): Resources , Conservation and Recycling E-waste: An overview on generation , collection , legislation and recycling practices, *"Resources, Conservation & Recycling,"* **122**, 32–42.

Larsson, H., & Bertilsson, H. (1995): Upgrading of recycled ABS: blends with polycarbonate, *Polymer Recycling.*

Linton, J. D., Klassen, R., & Jayaraman, V. (2007): Sustainable supply chains: An introduction, **25**, 1075–1082.

Lu, X. B., Ren, W. M., & Wu, G. P. (2012): CO 2 copolymers from epoxides: Catalyst activity, product selectivity, and stereochemistry control, *Accounts of Chemical Research,* **45**(10), 1721 –1735.

Melnyk, S. A., Sroufe, R. P., & Calantone, R. (2003): Assessing the impact of environmental management systems on corporate and environmental performance, **21,** 329–351.

Moore, C. J. (2008): Synthetic polymers in the marine environment: A rapidly increasing, long-term threat, *Environmental Research,* **108** (2), 131–139.

Narasimhan, R., & Carter, J. R. (1998): *Environmental Supply Chain Management* (Arizona St). Arizona: The Center for Advance Purschasing Studies.

OECD. (2017): *Extended producer responsibility,* available at http://www.oecd.org/env/tools-evaluation/extended producerresponsibility.htm, accessed 2 April 2019.

Pagell, M., & Krumwiede, D. W. (2004): Does the Competitive Environment Influence the Efficacy of Investments in Environmental Management? (1961), 30–39.

Prashanth, L., Chitturi, R., Baddam, V. R., Prasad, L., & Kattapagari, K. (2015): A review on role of essential trace elements in health and disease. Journal of Dr. NTR University of Health Sciences, **4**(2), 75.

Reith, R. (2019): International Data Corporation. Framingham, Mass.

Revellio, F., & Hansen, E. G. (2017): *Value Creation Architectures for the Circular Economy A Make-or-Buy Analysis in the Smartphone Industry.*

Royer, S.-J., Ferro´n, S., Wilson, S. T., & Karl, D. M. (2018): Production of methane and ethylene from plastic in the environment, *PLoS ONE*, **13**(8).

Smith, S. (2015): *Global Engineering Plastics market - Segmented by Product type, Application and Geography - Trends and Forecasts* (2015-2020), available at https://www.prnewswire.com/news-releases/global-engineering-plastics-market--segmented-by-product-type-application-and-geography--trends-and-forecasts-2015-2020-300168275.html, accessed 2 April 2019.

Steinlechner, C., & Junge, H. (2018): Renewable Methane Generation from Carbon Dioxide and Sunlight, *Angewandte Chemie - International Edition*, **57**(1), 44–45.

Stobbe, L. (2017): *Screening and expert benchmark of smartphone design features in conjunction with Circular Economy metrics*, Berlin, Darmstadt.

Wasmus, S., Cattaneo, E., & Vielstich, W. (1990): Reduction of carbon dioxide to methane and ethene-an on-line MS study with rotating electrodes, *Electrochimica Acta,* **35**(4), 771–775.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005): Global perspectives on e-waste, *Environmental Impact Assessment Review,* **25**(5 SPEC. ISS.), 436–458.

Wright, R., & Elcock, K. (2006): *The RoHS and WEEE Directives: Environmental Challenges for the Electrical and Electronic,* 9–24.

Zhu, Q., Sarkis, J., & Lai, K. hung. (2008): Confirmation of a measurement model for green supply chain management practices implementation, *International Journal of Production Economics,* **111**(2), 261–273.

Zsidisin, G. A., & Hendrick, T. E. (1998): Purchasing's involvement in environmental issues: A multi-country perspective, *Industrial Management and Data Systems,* **98**(7).

Practitioner's Section

The smart-up ecosystem: Turning Open Innovation into smart business

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The Fourth Industrial Revolution is changing the world. IT-based technologies start to have an increasing impact on the chemical industry. Incumbents need to smart-up in order to stay competitive. Especially small and medium-sized enterprises (SMEs) are facing a tough challenge as they lack resources and expertise in implementing Industry 4.0. In this paper, the smart-up ecosystem is introduced: a conceptual model that offers SMEs guidance on how they can move, step by step, from an uninformed situation into smart business. Based on initial experiences using the model in practice, some critical points along this smartification journey are highlighted.

1 Introduction

Innovation has repeatedly been identified as a vital driver for the European chemical industry. Firms need to innovate in order to stay sustainably competitive. Universities are often seen as an important source of knowledge for (more) radical innovation. Over the last decades, however, scientific findings turned out to be too far from market application to be directly interesting for incumbents. This gap in the innovation process has been filled up by start-ups. These young, technology-based firms play an important role as (temporary) carrier of new, innovative developments (Clayton et al., 2018). Once a start-up grows and the technological risk decreases, it becomes an interesting collaboration partner or acquisition target for established firms. These incumbents can enrich their business portfolio this way, while minimizing the risk of failure that is normal in the innovation process. Nouryon, in this context, organizes an annual worldwide challenge for start-ups to uncover sustainable opportunities for the company (Imagine Chemistry). This new way of growing innovative ideas via start-ups and the resulting interaction with incumbents perfectly fits the current open innovation era (Chesbrough, 2003). As chemical firms are no longer able to cover the innovation process alone, they need to interact with external sources of knowledge and new paths to the market.

Innovation ecosystems play a vital role in enabling technology-based start-ups to be created and to get interaction with incumbents ongoing. Bearing Silicon Valley in mind, many European countries have started to build their own ecosystems (Rissola and Sörvik, 2018). In the Netherlands (ChemieLink), a fine-grained innovation ecosystem was built to boost chemical start-ups. The backbone of this network – called ChemieLink– are ten innovation labs (ilab) and seven centres for open innovation (coci). The ilabs are physical locations equipped to allow chemical start-ups to take their first business steps. These incubators were realized in the vicinity of universities in order to smoothen the step for entrepreneurial researchers to start their own business. Once the start-up grows, it can easily move to a so-called coci: a brown-field site equipped to accommodate chemical scale-ups. At these locations, the incumbent present (e.g. DSM, SABIC) agreed to act as custodian, helping the young firm to up-scale their business and access international markets. At this moment, approximately 300 young, innovative firms are located at the 17 'ChemieLink'-hotspots in the Netherlands. These locations together literally bridge the gap between scientific findings and market application. There is, however, no time to rest on laurels as a new, significant challenge is imminent.

2 The Rise of the smart chemical industry

Innovation ecosystems and their inhabitants around the world are currently facing the breakthrough of IT-based technologies, giving rise to the Fourth Industrial Revolution. The First Industrial Revolution - starting halfway the 18th century - introduced water and steam power to enable mechanization. It substituted agriculture for industry as the backbone of the economic structure. Nearly a century later, the Second Industrial Revolution used electric power to create mass production. The chemical industry, for example, began to grow and brought society new products like dyes and fertilizer on a large scale (Hoffman and Budde, 2006). Innovations like the transistor and microprocessor subsequently paved the way for the Third Industrial Revolution in the second half of the 20th century. Production was automated within factories by means of computers and telecommunications. Currently, the Fourth Industrial Revolution is building on the Third. According to Klaus Schwab (2017), the founder and CEO of the World Economic Forum, this new revolution is characterized by the rise of cyber-physical systems. Emerging technology fields such as robotics, industrial internet of things, unarmed aerial vehicles and machine learning will result in fusion of the biological, physical and digital world.

In short, the Fourth Industrial Revolution is said to force firms to become digitally connected: both within the factory as well to the outside world (e.g. along the value chain). A so-called smart factory is envisioned 'a fully connected and flexible system - one that can use a constant stream of data from connected operations and production systems to learn and adapt to new demands' (Burke et al., 2017). If firms fail to grasp the digital transformation, their business might become disrupted. Examples are already seen in the service (or tertiary economic) sector: retailers lost clients due to online stores, tourists prefer Airbnb to conventional hotels and regular taxi companies suffer from Uber. In order to try to overcome this situation in the manufacturing (or secondary economic) sector, countries started campaigns to prepare their established manufacturing firms. In Europe, Germany was one of the first movers and coined the digital transition 'Industry 4.0' (Kagermann et al., 2012). The Netherlands followed in 2014, included new manufacturing techniques like additive printing and robotics, and labelled it 'Smart Industry'. Currently, more than half of the EU-countries are addressing the digital transformation in manufacturing industries at a national scale (European Commision).

This attention is justified: the impact of the Fourth Industrial Revolution on the chemical industry is expected to be enormous. The Digital Transformation Initiative (DTI) team by the World Economic Forum and Accenture (2017) estimated, based on the value-at-stake methodology, the cumulative economic value for the chemistry and advanced materials sector to range from about \$310 billion to \$550 billion over the period 2016-2025. Moreover, in terms of non-economic benefits, digitization has the potential to reduce CO_2 emissions by 60-100 million tonnes. Regarding firm-level, the DTI-team identified three themes that are expected to have a great impact. First, the digitalization of the firm itself: the efficiency of core operating functions like R&D and plant operations can be further increased using digital simulation technologies. Second, chemical firms will be able to improve their customer interaction (e.g. understanding customers' needs by social media mining) and develop new digitally enabled offerings. A chemical company will, for example, no longer sell fertilizers, but guarantees its customers a certain yield; or years of preservation instead of paint (Yankovitz et al., 2016). The third theme that is expected to have a great impact at the firm-level is collaboration in innovation ecosystems.

The interest in innovation ecosystems has increased in the last couple of years. Not only firms, but also governments and knowledge institutes are exploring the concept. However, while insights regarding the other themes (i.e. digitization of production and sales) emerge rapidly, the ecosystem concept remains rather vague. This ambiguity was recently addressed in a literature review (Suominen et al., 2018).

The researchers identified seven sub-clusters within ecosystem research; clusters such as knowledge ecosystems, the development of ecosystems and digital business ecosystems. The sub-clusters, however, overlapped when analyzing the most cited contributions. An indication, according to the scholars, that the research domain is still premature. The resultant lack of a practical ecosystem concept is a loss for chemical firms. It was hypothesized that those firms that are able to manage the complexity related to the ecosystem will strengthen their competitive advantage (Leker and Utikal, 2018). As complexity will only increase in the coming years due to digital technologies and the need for incumbents to interact with, for example, start-ups as source of innovative developments, a hands-on ecosystem model is highly desirable.

3 The smart-up ecosystem

In order to develop a concrete ecosystem model, one has to interweave the involvement of multiple stakeholders - both public and private - into the concept of open innovation. Only then all participants will experience enough recognition to join in and strive for collaboration in a symbiotic way. In this paragraph, such an ecosystem model - entitled the smart-up ecosystem - is introduced. This model was developed by adding insights from practice and theory to an existing ecosystem concept. However, before constructing the smart-up ecosystem, some methodological considerations and the existing concept (i.e. innovation ecosystem canvas) are briefly described.

3.1 Methodological considerations

In the last couple of years, the author of this manuscript was enrolled as senior project manager in multiple projects dealing with the analysis, development and management of ecosystems. The main inhabitants of these ecosystems were established firms from the manufacturing sector. Firms that were facing the digital revolution. In 2017, for example, the project management included the coordination of the national Smart Industry initiative in the eastern part of the Netherlands. In practice, a network of more than 25 organizations (industry associations, governmental organizations, knowledge institutes, etc.) was managed and developed. The aim of this network - called BOOST (Smart Industry) - was to align, and where possible combine, the more than 500 support options of the network members for regionally-based SMEs (circa 4,500 firms in total). That way, the overview of options for SMEs would become clearer and stronger. As a project manager of this network, it was needed to act as a reflective practitioner (Schon, 1983): in order to get the stakeholders on the same page, it was required to go back and forth from practical discussions and experiences to theoretical conceptions. The smart-up ecosystem model that was developed in this period to align all support options was subsequently fine-tuned during a quick scan - on behalf of Holland Chemistry (Holland Chemistry) - on the smart chemical industry in 2018.

3.2 The innovation ecosystem canvas: From concept to product

The development of ChemieLink, the fine-grained innovation ecosystem to boost young, innovative firms in the Dutch chemical industry, is described in detail by van Gils and Rutjes (2017). They describe a five-year period in which a project team helped to realize an incubator (so-called ilab), tailored to the specific needs of chemical start-ups, in the vicinity of almost every Dutch university with a chemistry department. The rationale was that entrepreneurial chemistry students could hence start their firm almost as easily as, for example, a fellow student working on IT-innovation. Later on, the project team also assisted the creation of several brownfield locations for chemical scale-ups (so-called coci). That way, start-ups which outgrew the incubator would not lose too much time finding a suitable location to scale-up. The firm Flowid, for example, was born in the *ilab* of the Eindhoven University of Technology, but constructed a pilot plant at the *coci* 'Brightlands Chemelot Campus' in Sittard-Geleen (Flowid). At this moment, ChemieLink encompasses ten ilabs and seven coci-locations. To keep a high level of knowledge sharing between all locations, a network-coordinator was appointed and a steering committee installed. Together they draw up the annual plan, consisting of seminars on chemical and entrepreneurial topics, meetings of business angels and joint promotional activities.

As a spin-off result of the work, the project team created the 'innovation ecosystem canvas' as a new method. The conceptual framework makes the changes explicit of four success factors for innovative activities alongside the technological development process. Based on the ideal type approach (Weber, 1947), the model shows for each technological development phase the best match for the innovator leading the team, business operations, facilities and funding (Figure 1). A researcher, for example, can best lead the team when working on a proof-of-concept, while an entrepreneur needs to be in charge once the 0-serie has to be introduced into the market.

Next to outlining an appropriate configuration in each development phase, the model helps to depict the position of the stakeholders in the open innovation process. The innovative heart itself already involves two partners of the Triple Helix: firms and academia. Regarding the latter, the 'heart' mainly denotes its research and valorization task. The eldest task – education - of academia as well as the (tasks of the) third Triple Helix partner, governmental organizations, are found when considering the preconditions that 'nourish' the innovative heart (OECD, 1999). These five preconditions directly influence the ecosystem by means of examples as listed below (Table 1).

The final insight the ecosystem model can provide is a visual overview of all support initiatives aimed at innovative activities in a geographical and/or thematic delineated ecosystem. By using the model as a canvas and plotting an initiative at the point on the model it addresses an overview arises. Dragon's Den, for example, is aimed at start-ups looking for funding, while an ilab covers the location need of start-ups. In other words: both initiatives are placed in the start-phase, however, Dragon's Den is plotted on the success factor 'funding', the ilab on 'facilities'. The resultant overview shows the options innovators have to get answers on specific challenges: you go to Dragon's Den to get funded, not to ask them for help on your location; while you visit an incubator for the exact opposite. These well-defined cross-sections of an ecosystem (incubator, business angel network, etc.) were entitled 'innovation biotopes' (van Gils and Rutjes, 2017). The resulting overview of biotopes turned out to be helpful for governments and entrepreneurs. Policy-makers could start working on the improvement of the innovation ecosystem from a helicopter view. Entrepreneurs, on their turn, could find their way easier to support initiatives. An aspect that is particularly appealing to SMEs as it somewhat relieves the lack of organizational capacity and resources

Figure 1 The innovative heart of an ecosystem (source: adapted from Van Gils and Rutjes, 2017).

Innovation phase / Sucess factor	Idea(tion)	Pre-seed	Start	Develop	Growth	Consolidate	Decline
Tech. idea	Conceptual idea *trl: 1**	Proof-of-concept *trl: 2-3* ('milligrams')	Prototype *trl: 4-5* ('grams')	O-series *trl: 6-7* ('kilograms')	Product *trl: 8-9* *('tons')*	Product portfolio	Product selection
Innovator	Fundamental researcher	Researcher	Entrepreneurial researcher	Researching entrepreneur	Entrepreneur	Manager	Turnaround manager
Bus. operat.	Imperfection market/ technolgy	Feasibility study market/ technolgy	Exploration market and business model	Market launch	Market break-through	Market share	Market loss
Facilities	University knowledge institute	Public-private-partnership	Incubator corporate lab	Accelerator business park	Pilot plant brown-field	One or more plants	Plant divestment
Funding	Scientific/ resarch funding	Pre-seed funds (≤ 25 k€)	Seed funds (≤ 250 k€)	1st round (≤ 2.5 M€)	2nd / 3rd round (≤ 25 M€)	Share swap	(Partially) taken over

* trl = technological readiness level

Table 1 Preconditions influencing the innovation ecosystem (source: own representation).

Precondition	Example from practice
Macroeconomic and regulatory context	- Innovation policy (cf. stimulation of startups) - Exemption permitting specific activities
Communication infrastructures	- Business networks - Promotional activities (cf. Holland Chemistry)
Factor market conditions	- Shared facilities (cf. fieldlab on predictive maintenance) - Digital/ IT-infrastructure
Product market conditions	- Governmental launching customership - Acquiring new partners for the ecosystem (cf. EMA)
Education and training system	- Qualified young professionals - Lifelong learning programs (cf. human capital agenda)

they face when engaging in open innovation (Brunswicker and Vanhaverbeke, 2014).

3.3 The challenge for SMEs: From uninformed to action

The ecosystem canvas turned out to be a powerful tool: several Dutch regions that focus on chemistry were mapped and discussions between stakeholders became - as they shared the same concept of an ecosystem - more to the point. In Southeast Drenthe, for example, the canvas helped to determine a *blind* spot in the support portfolio very accurately. Subsequent discussions with the regional triple helix led to an additional public investment in business development for chemical firms. This capacity was especially aimed at scale-up firms located at, or in the vicinity of, the *coci* in Emmen, being the physical hotspot of the regional chemistry cluster (Chemical Cluster Emmen). That way, the innovation ecosystem got a targeted boost. However, despite the added value in ecosystems covering predominantly young firms, the canvas it turned out to be less applicable in ecosystems consisting of mainly technology-based incumbents. Unlike *digitally-born* start-ups that almost automatically embrace new IT-technologies, incumbents still need to get fit first before they can adopt the digital revolution. Whereas corporates are able to fill out this need by installing a team overnight (e.g. Evonik established a digitalization subsidiary (Evonik)) or by cooperating with a start-up (e.g. Sabic cooperates with Ovinto to constantly track-and-trace its European fleet of 500 rail tank cars (EPCA)), established SMEs lack both resources and expertise in implementing Industry 4.0 (Schröder, 2016; Müller et al., 2018).

Established SMEs, while facing the digital revolution, are often ‘doing things like they have always done’. Whereas some of them are able to adopt new IT-technologies by means of learning-by-doing, other firms seem to be cramped. From their viewpoint, it seems almost impossible to make the right choice in the abundance of opportunities the revolution offers; let alone the implementation process (Smetsers, 2016). These firms clearly need some guidance through the transition process - going back from existing products to innovative concepts - even though it is impossible to show them the way individually. The main challenge: to get the firms out of their uninformed situation into an action modus. A process of learning that needs to be taken step-by-step in order not to lose them during the transition process. Despite the huge amount of recent literature on (organizational) learning processes, in daily practice the time-honored marketing funnel by Strong (1925) is still a suitable starting point. It discerns four phases someone needs to experience successively in order to go from getting acquainted with new possibilities to actually investing in them. The four phases of this journey are: creating awareness, generating interest, causing desire and, finally, taking action (the acronym is AIDA).

To make the AIDA-funnel applicable for the digital revolution, it is needed to interweave the smart industry dimensions into the transition process. In practice, three main dimensions are discerned: smart technology, smart working and smart business (Table 2). Firms need to act on all three in order to really smart-up. After all, buying a 3D-printer, but lacking the staff to operate it or a business model to turn its possibilities into revenue, will lead to failure. In other words: if one out of three is absent, successful implementation will be hard to achieve. Regarding the three dimensions, the same success factors as in the ecosystem canvas appeared relevant; however, the use of 'change agent' and 'change recipient' (Oreg et al., 2018) is more appropriate than 'innovator and team'.

The combination of the AIDA-funnel and the three SI-dimensions leads to a basic model that shows the phases a firm has to undergo to exchange their uninformed situation for action. In practice, initial awareness (first phase) about the digital revolution arises in a variety of ways: by talking to fellow entrepreneurs, reading the newspaper, listening to a customer, etc.. In other words, a spark - like in the model of Kline and Rosenberg (1986) - starts the firm's smart-up process in most cases. Interest in a certain smart technology (big data, robotics, etc.) then normally evolves. The edited AIDA-funnel shows that one has to think, next to consulting knowledge sources on the technology, about how to involve the firm's business and human part in this early 'interest' phase. For example by considering questions like: how will the firm profit from the investment in time? Does it merely offer possibilities for process optimization or also for product innovation? And which departments need to be involved? It is wise to already notify HR-officers and start a discussion about new skills? In reality, however, the next 'desire' phase is often entered after only completing the technological scan, increasing the risk of a failed implementation. In other words: a 3D-printer that gets dusted in a factory, an undesirable scenario thinking about the scarce resources SMEs have to smart-up (Schröder, 2016).

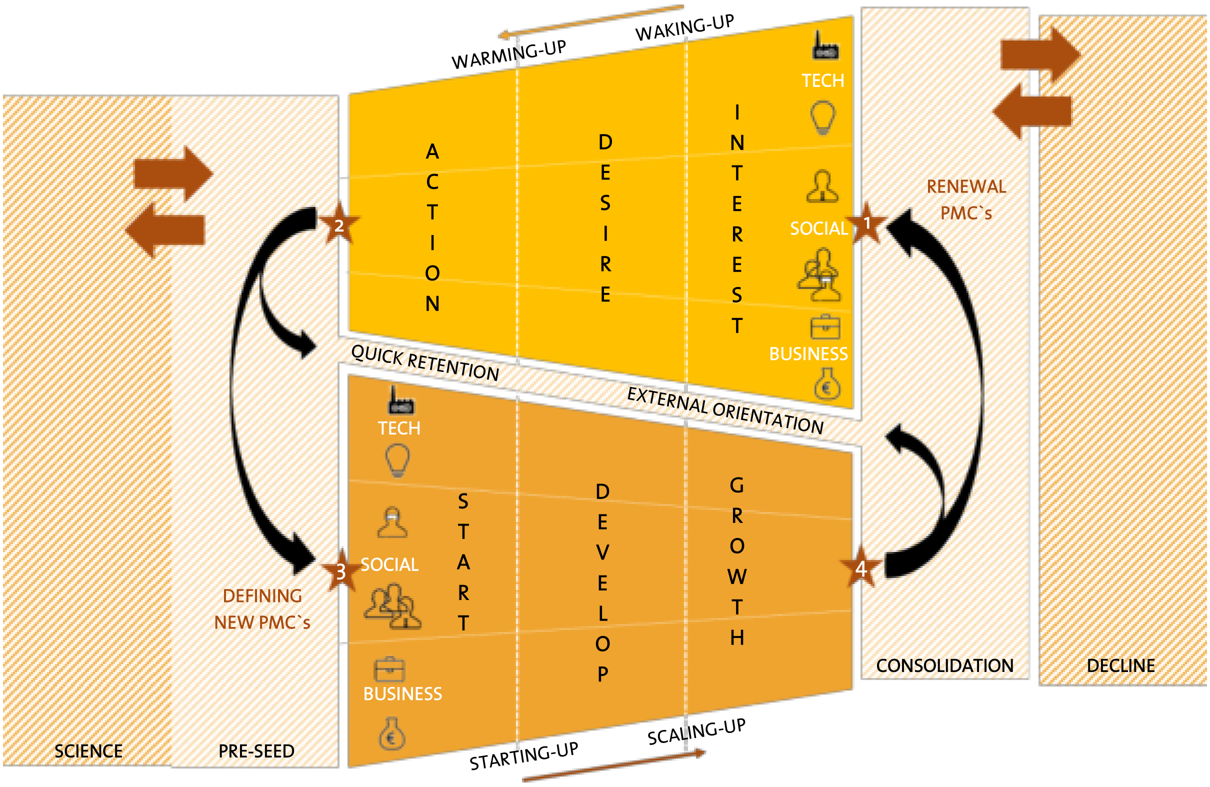
3.4 The smart-up ecosystem: Innovating and learning

The innovation ecosystem model turned out to be a powerful tool, but its applicability in ecosystems consisting predominantly of technology-based incumbents was limited. It did not show how these firms, being innovators or laggards (Rogers, 1995), could renew themselves in the digital era. The innovation ecosystem model specified the process from concept to product, but not from existing product to new concept. In the previous paragraph, the way back was discussed. By enriching the AIDA-model with the three smart industry dimensions, a funnel originated that roughly outlines this route and helps to overcome opportunistic investments in smart technologies. When combining this 'way-back' funnel with the existing ecosystem canvas, the skeleton of the smart-up ecosystem arises (Figure 2). Central to the model are the innovating (ecosystem canvas; below) and learning (edited AIDA-funnel; above) path-

Table 2 Dimensions of the smart industry transformation within firms (source: own representation).

SI-dimension	Focus and success factors	Example from practice
Smart technology (technological innovation)	Technology (product, process/ facilities)	- Machine learning - Virtual/ augmented reality - Robotics
Smart working (social innovation)	People (change agent, change recipient)	- IT-skills - Computational thinking - Collaborative competences
Smart business (business model innovation)	Organization (business operations, funding)	- Servitization/ x as a service - Transaction platforms - Circular business models

Figure 2 The smart-up ecosystem (source: own representation).



ways, which are connected by the pre-seed (left) and the consolidation phase (right). In both pathways, the corresponding phases as well as the SI-dimensions (i.e. people, technology and organization) are illustrated. On the two outsides are the phases that focus, on the one hand, on discovering new fundamental insights (idea phase) and, on the other, activities to avert the downfall of a firm (decline phase). [1]

In explaining the logic of the model, it is best to think about a firm that is in the consolidation phase. For example, a medium-sized firm that is producing a range of plastic products for a relatively steady group of clients. The firm possesses several injection moldings machines, has a clear focus on its running business and is acquainted with its competing colleagues. One day, at an international fair, the firm's representatives are confronted with an new entrant: a start-up says to be able to print their less complex products for half the time and costs. Initially, the representatives laugh about it. However, a year later a regular client leaves the firm for the start-up. The entrant has found its way into the incumbent's clientele. Starting from the less-profitable segment, the start-up aims to improve its performance and move upmarket. The incumbent is being disrupted (Christensen et al., 2015). Where earlier 'awareness sparks' - e.g. the fair, articles about 3D printing - stayed undetected, the loss of the client makes the CEO to start embracing the digital revolution (Figure 2: star #1). After an intensive process in which, among others, seminars are attended to grow the interest within the firm, workshops are followed by the management team to find out the most value added solution (desire phase) and skills are gained in a fieldlab (Smart Industry) by co-workers (action phase), the CEO decides to invest in 3D-printing (star #2). However, not to print clients' products –like competitors do– but to produce plastic molds. Instead of buying a standard 3D-printer that can be used on occasional cus-

[1] The preconditions as enlisted in Table 1 also nourish the smart-up ecosystem, but are left away for clarity reasons.

tomer request by the trained co-workers (i.e. quick retention; intermediate path), the CEO decides to take it bigger and starts a full-blown innovation process (i.e. focus on the lower funnel). By producing plastic molds using 3D-printing, the firm will be able to better serve its customers: it can speed up the process from design to production, significantly lower the costs and offer small(er) series of plastics products as the high investments for regular molds are avoided. In order to realize the proof of concept - the level of technological development consistent with the pre-seed phase - the firm has to find co-development partners. On the one hand, to morph a commercially available 3D-printer to the specifications of the firm and, on the other, to develop a value proposition. The latter should include, according to the CEO, a digital assistant to increase the online connectivity with potential clients: a secure software platform that makes it possible for any customer to upload its 3D-file and receive a price indication directly. In other words: the chemical firm is looking to integrate several disciplines (e.g. IT, engineering, material science, business development), which are not all available in-house, to create a 'Neue Kombination' (Schumpeter, 1934). After joining network meetings to search for partners, discussing the best legal form for cooperation (project, start-up, etc.) and many other things, an internal project team - in close co-creation with external experts on IT and business development - is installed (star #3).

The route of starting-up and scaling-up begins. An innovation process, full of trial and error, follows in order to reach the desired technological product and sound value proposition. At the end of the growth phase, the project team presents the 3D-printer and shows how the digital assistant can help customers to order online the production of their plastic mold. This milestone marks a new point of strategic options for the chemical firm (star #4). On the one hand, the CEO could see it as the end point, adding the new proposition to the existing portfolio and trying to earn back the investments as soon as possible. On the other, he could also hold on to the innovative mood and stay externally oriented (i.e. taking the intermediate path). That way, the firm might bump into external partners like start-ups with new materials to print with or novel software solutions. According to Whitesides (2015), the latter option is the right way to go. He states (p. 3197) that '[the chemical] industry must either augment its commodity- and service-based model to re-engage with invention, or face the prospect of settling into a corner of an industrial society that is comfortable, but largely irrelevant to the flows of technology that change the world.' In other words: being connected to early -stage developments at external partners is not only important for big corporates, but also for established SMEs if they are looking to continuously smarten-up their business in the digital era.

4 Learnings from the use of the model in practice

The smart-up ecosystem combines the pathways of innovating and learning. It provides incumbents guidance on how they can move, step by step, from an uninformed situation into a mode of realizing smart business. Based on initial experiences using the model in practice, some critical points along this *smartification* journey are highlighted. On the one hand, some extra considerations regarding the route mapped for firms are made. What are, for example, important challenges firms may encounter during the smartification journey? On the other hand, the model as canvas tool for (semi)public organizations is explained. How can it be used to upgrade an innovation ecosystem to a smart-up ecosystem?

4.1 The private perspective

The process of adopting smart technology and using it to increase the competitiveness is challenging for an established SME. However, being confronted with *digitally-born* competitors, while facing the end of the lifecycle, makes smartification a journey one has to undertake. Four critical points along that journey - like the strategic choice to stay externally oriented - were already highlighted in the previous paragraph. Two additional aspects, as they were witnessed in practice, need to be addressed:

1. The need to focus on the business dimension to realize a smooth shift to the desire phase;
2. The formation of a 'coalition of the making' to enter the start-phase.

Regarding the first aspect, it is important to concentrate on the type of activities that are in general available for incumbents walking along the learning path. Once convinced about the need to embrace the digital revolution, chemical firms bump into countless opportunities to build up their interest. They can visit multiple fairs and conferences each day. At those - often rather large scale - gatherings, firms are informed about the state-of-the-art on a particular topic. However, the employee himself has to translate the information received into possibilities for his firm. A difficult task, which becomes even harder when the employee returns to the firm and is confronted with all kind of urgent request by colleagues and clients. In many cases, the inspiration gained during a conference slowly fades away. A linkage to smoothen the shift to the next phase is to get a clear sense of the business potential in the interest phase. Success stories from other firms, for example, stressing that element turned out to help convincing management to continue to the desire phase. A phase in which the anonymity of a large-scale conference is absent as workshops, master classes and scans are usually the type of activities found in practice. Small teams of employees start working on the case of their own firm. The future business model, for which circularity could be a stimulating angle of approach, offers a good frame of reference when exploring the technology and human dimension.

With skills and expertise gained in the action phase, the chemical firm enters the preseed phase. To realize the proof-of-concept of the envisioned innovation, the firm has to find partners. After all, the innovation combines at least two disciplines (i.e. chemistry and IT), but probably even more. The technological development in this phase can often, particularly when a research institute is involved, be financed using public research funds. As a result, the formation of a coalition is feasible in most cases: firms are willing to join in as the financial risk is relatively low. A critical point is reached once the proof-of-concept is ready. The precompetitive part is finished and public organizations have to give up their active role as a more commercial phase starts. The existing 'coalition of the willing' needs to be converted into a 'coalition of the making': a group of mainly private partners that needs to agree on a greater financial contribution (and risk) to develop the product. In practice, this implies that firms have to choose: either they join in or they are out. A difficult choice to make as not all aspects of the business case might be clear. Who should take the lead? What are the future prospects? Are all skills on board? What collaborative arrangement fits best? Questions that have to be answered; preferably not too late to prevent a break-up anyway. However, a manual is lacking.

4.2 The public perspective

The smart-up ecosystem model turned out to be helpful from a (semi)public perspective as well. The design and development of innovation ecosystems is often in hand of a regional and/or sectoral triple helix. Governments facilitate, in close collaboration with firms, industry associations and knowledge institutes, programs aimed at stimulating entrepreneurship and business growth. The innovation ecosystem canvas already proved to be a powerful tool in this situation: it enabled visualization of ecosystems, especially those created for start-ups and scale-ups, by plotting each initiative on the topic it addresses. The resulting overview improved discussions between stakeholders and helped to make better choices regarding new programs. Furthermore, the alignment between existing programs like accelerators, incubators and bootcamps was boosted and, accordingly, the bigger picture became easier to explain to entrepreneurs looking for support. The smart-up model offers similar possibilities. To be more precise, it helps a regional and/or sectoral triple helix to develop programs and instruments that established SMEs can use during their smartification journey. Or, in terms of a higher aggregation level: the model can help a triple helix to upgrade an innovation ecosystem –aimed at creating start-ups and growing scale-ups– to a smart-up ecosystem that boosts all types of firms.

Holland Chemistry, the triple helix for the Dutch chemical industry, is working on this upgrade. The quality of the current innovation ecosystem is already of a high level. It covers, for example, ten ilabs, seven coci-locations, grants for start-ups and challenges like 'Image Chemistry'. With regard to the upgrade to a smart-up ecosystem, already quite a few initiatives are in place. The portfolio includes, for example, a knowledge sharing platform

‘Molecules Meets Digits’, a fieldlab on condition -based maintenance and an action agenda on digital skills. The recent quickscan was a next step in the process that should lead to the smart chemical industry. The goal was to explore where the ecosystem could be further strengthened. By mapping developments and identifying low-hanging fruit - for example, use of VR for safety training - as well as long-term, highly promising opportunities (e.g. digital twinning), new insights were gained. The upgrade process now continues with the design of the optimal situation, bearing in mind these insights and the smartification journey SMEs face. The main challenge will be to find the right balance between (fundamental) research, needed to get accurate understandings, and innovative development and co-creation that is required to keep pace with the outside world.

5 Conclusion

The Fourth Industrial Revolution is changing the world. After disrupting the service sector (e.g. retail, hotel and taxi business), IT-based technologies like robotics and artificial intelligence are starting to have more and more impact on the manufacturing sector. Chemical incumbents need to smart-up in order to survive: *digitally-born* startups are on their way to disrupt existing markets. Where corporates appear to able to fill out their smartification journey by installing capable teams overnight or by collaborating with these startups, established SMEs in the chemical industry face a serious challenge. These firms lack both resources and expertise in implementing Industry 4.0. From their viewpoint, it seems almost impossible to make the right choices in the abundance of opportunities the digital revolution offers. In this paper, the smart-up ecosystem was presented for support. The conceptual model offers incumbents guidance on how they can move, step by step, from an uninformed situation into a mode of innovating. It shows how three important smart industry dimensions (technology, people and organization) are to be addressed throughout the transition process. The first experiences in practice showed that the model is useful for discussions with chemical SMEs: it helps them to better oversee the transition process which prevents them from dropping out early. Moreover, the model helped a triple helix alliance like Holland Chemistry in defining how they can upgrade their current innovation ecosystems - aimed at creating startups and growing scale-ups - to a smart-up ecosystem that boosts all types of firms. A key challenge was signaled in the pre-seed phase where ‘coalitions of the willing’ that are created around a certain idea need to be converted into ‘coalitions of the making’. Future research will address this point in order to resolve this disturbance in the process of turning open innovation into smart business.

References

Brunswicker, S., Vanhaverbeke, W. (2015): Open innovation in small and medium‐sized enterprises (SMEs): External knowledge sourcing strategies and internal organizational facilitators, *Journal of Small Business Management*, **53** (4), p. 1241-1263.

Burke, R., Mussomeli, A., Laaper, S., Hartigan, M., Sniderman, B. (2017): *The smart factory: Responsive, adaptive, connected manufacturing*, Deloitte University Press, New York.

Chemical Cluster Emmen, available at www.chemicalclusteremmen.eu, accessed 31 January 2019.

ChemieLink, available at www.chemielink.nl, accessed 31 January 2019.

Chesbrough, H. (2003): *Open Innovation: the new imperative for creating and profiting from technology*, Harvard Business School Press, Boston.

Christensen, C., Raynor, M., McDonald, R. (2015): Disruption, *Harvard Business Review*, **93** (12), p. 44-53.

Clayton, P., Feldman, M., Lowe, N. (2018): Behind the scenes: Intermediary organizations that facilitate science commercialization through entrepreneurship, *Academy of Management Perspectives*, **32** (1), p. 104-124.

Digital Transformation Initiative (2017): *Chemistry and Advanced Materials Industry, White Paper*, World Economic Forum and Accenture, Cologny/Geneva.

European Commission, available at ec.europa.eu/digital-single-market/en/coordination-european-national-regional-initiatives, accessed 31 January 2019.

European Petrochemical Association, https://newsroom.epca.eu/report-digitisation-in-the-petrochemical-supply-chain/, accessed 31 January 2019.

Evonik, available at https://corporate.evonik.com/en/pages/article.aspx?articleId=322, accessed 31 January 2019.

Flowid, www.flowid.nl, accessed 31 January 2019.

Hofmann, K., Budde, F. (2006): Today's Chemical Industry: *Which Way Is Up?,* Wiley-VCH, Weinheim.

Holland Chemistry, www.hollandchemistry.nl, accessed 31 January 2019.

Imagine Chemistry, www.imaginechemistry.com, accessed 31 January 2019.

Kagermann, H., Wahlster, W., Helbig, J., Hellinger, A., Karger, R. (2012): *Im Fokus: das Zukunftsprojekt Industrie 4.0: Handlungsempfehlungen zur Umsetzung, Bericht der Promotorengruppe Kommunikation,* Forschungsunion, Berlin.

Kline, J. K., Rosenberg, N. (1986): An Overview of Innovation, in: Landau, R., Rosenberg, N., (ed.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth,* Academy of Engineering Press, Washington DC, p. 275–305.

Leker, J., Utikal, H. (2018): Re-inventing chemistry – an industry in transition, *Journal of Business Chemistry.*

Müller, J., Buliga, O., Voigt, K. (2018): Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0, Technological Forecasting and Social Change, **132**, p. 2-17.

Oreg, S., Bartunek, J., Lee, G., Do, B. (2018): An affect-based model of recipients' responses to organizational change events, *Academy of Management Review,* **43** (1), p. 65-86.

Organisation for Economic Co-operation and Development (1999): *Managing national innovation systems,* OECD Publishing, Paris.

Rissola, G., Sörvik, J. (2018): *Digital Innovation Hubs in Smart Specialisation Strategies,* Publications Office of the European Union, Luxembourg.

Rogers E.M. (1995): *Diffusion of innovations*, The Free Press, New York.

Schon, D. (1983): *The reflective practitioner,* Basic Books, New York.

Schröder, C. (2016): *The Challenges of Industry 4.0 for Small and Medium-sized Enterprises,* Friedrich Ebert Stiftung, Bonn.

Schumpeter, J. (1911): *The Theory of Economic Development,* Harvard University Press Cambridge.

Schwab, K. (2017): *The fourth industrial revolution,* Crown Business, New York.

Smart Industry, available at www.smartindustry.nl/fieldlabs, accessed 31 January 2019.

Smart Industry, available at www.smartindustryoost.nl, accessed 31 January 2019.

Smetsers, D. (2016): *Smart Industry Onderzoek 2016,* Report, Kamer van Koophandel, Utrecht.

Strong, E.K. (1925): Theories of selling, *Journal of Applied Psychology,* **9**, p. 75-86.

Suominen, A., Seppänen, M. and Dedehayir, O. (2018): A bibliometric review on innovation systems and ecosystems: a research agenda, *European Journal of Innovation Management* (early cite).

Yankovitz, D., Kreutzer, B. and Bjacek, P. (2016): *Chemical Industry Vision 2016,* Report, Accenture Chemicals, New York.

Van Gils, M.J.G.M., Rutjes, F.P.J.T. (2017): Accelerating chemical start-ups in ecosystems: The need for biotopes, *European Journal of Innovation Management,* **20** (1), p. 135-152.

Weber, M. (1947): *The Theory of Social and Economic Organization,* Oxford University Press, New York.

Whitesides, G. (2015): Reinventing chemistry, *Angewandte Chemie International Edition,* **54** (11), p. 3196-3209.

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Research Paper

Managing product variety under operational constraints: A process-industrial outlook

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Using a newly developed conceptual framework on “platform-based design of non-assembled products,” the process-industrial applicability of the framework in production and product design was investigated. In a survey of Nordic process industries the research instrument included a comprehensive questionnaire designed to stimulate respondents to act as “multiple informants”. The results indicate that the presented framework challenged company paradigms and working practices, but acknowledged the applicability of many components in the new framework. Moreover, the new findings suggest that the framework additionally can be deployed as an instrument in an assessment of corporate strategic production capabilities. The framework can already serve as a “theoretical coat hanger” for analyzing current company practices, but moreover as a point of departure for company introduction of platform-based production philosophy and a platform-based design of non-assembled products. Apart from the framework used in this study, publications in this area are scarce. The findings fulfill the criteria for a theoretical contribution since the results have both originality and high utility for academics as well as practitioners.

1 Introduction

Many companies in assembly-based manufacturing industries have long invested in the concept of “platform-based product family design” to provide sufficient variety to the market, while maintaining economies of both scale and scope within their innovation and manufacturing capabilities (Jianxin et al., 2007, Robertson and Ulrich, 1998). The concept is generally defined as “a set of sub-systems and interfaces that form a common structure from which a stream of derivate products can be efficiently developed and produced” (Meyer and Lehnerd, 1997). The need for a platform-based product family design in the production of assembled products in manufacturing industries today is indisputable. However, the development of a product platform and its derived family of products is impacted by the heterogeneous nature of the products (Meyer and Lehnerd, 1997).

The cluster of industries generally called the “process industries” spans multiple industrial sectors and generally includes petrochemicals and chemicals, food and beverages, mining and metals, mineral and materials, pharmaceuticals, pulp and paper, steel and utilities (Samuelsson et al., 2016). One of the principal differences between companies in the process industries and those in other manufacturing industries is that the products supplied to them, and often delivered from them, are materials or ingredients rather than components or assembled products (Flapper et al., 2002, Frishammar et al., 2012). In a review of the extant literature on platform-based design, only one article (Meyer and Dalal, 2002) related to a process-industrial context was found.

The homogenous nature of products manufactured in the process industries, as well as the intimate coupling between raw materials, production processes and products (Samuelsson et al., 2016), necessitates a well-integrated production and product design philosophy. In a recent study (Lager, 2017), it was concluded that current theoretical frameworks on platform based development of assembled products are not applicable in the process industries. In the latter, a novel conceptual framework for “platform-based production and design of non-assembled products” was developed, introducing a new approach on production and product development in the process industries.

Because of that, it was deemed of interest to inquire in-depth knowledge about present process-industrial awareness or possible use of such an approach, but also to further investigate the industrial applicability of the new construct. To that end, the concepts in the framework was further developed into a questionnaire that was utilized in a survey of the Nordic process industries. The survey results are presented in this study and the content is organized as follows.

In the next section, a frame of reference is given and the previously presented conceptual framework used in this study is introduced. The research strategy and design are then introduced, including the study population and the survey. In the main part of the article, empirical findings from the survey are presented, including comments from the respondents. The research results and limitations are then discussed. Finally, management implications are put forward together with general conclusions from the study.

2 A frame of reference

To facilitate the reading experience, the rather voluminous questionnaire deployed in the survey has been integrated with the presentation of the empirical findings. Because of that, the following frame of reference only introduces the reader to the “core” of the conceptual model and the ideas contained in the framework.

To provide sufficient variety to the market, while maintaining efficiency within their innovation and manufacturing activities, is of interest to companies in assembly-based manufacturing industries as well as in the process industries.

The literature on product variety is largely related to the issue of production and product flexibility (Jack and Raturi, 2003); generally either taking a product design perspective (Belt et al., 2015, Park et al., 2008, Luo et al., 2010), or the development of mathematical models for operational optimization (Daie and Li, 2016, Wilson and Ali, 2014). Postponement, and to maintain products as long as possible is one solution to deal with the increasing variety problem, which was found to be of interest in the food processing industries (Van Campen and Van Donk, 2014). Kahn (1998) provides a general review of the topical area and on using high-variety strategies for a dynamic relationship with customers see e.g. Kahn (1998).

One solution for managing product variety in manufacturing industries is to employ platform-based product design. A basic requirement in platform-based product family design in assembly-based industries is the decoupling of design elements to achieve separation of common elements (platform) from differentiating (non-platform) elements (Halman et al., 2003). In those industries, a modular design with well-designed interfaces is a proven industrial practice to employ, when related process and supply platforms should be developed (Suh, 2001).

Recently, platform-based product family design of assembled products was reconceptualized into a theoretical framework for platform -based design of non-assembled products (Lager, 2017), where platform-based product design was defined as shared logic in product design activities. The conceptual framework relied on early contacts with four informants that further ascertained that “platform-based production design of non-assembled products” was probably a novel construct in several sectors of the process industries. Thus, it was proposed that a platform-based production philosophy and platform-based design of non-assembled products should rely on product platforms, process platforms, and raw-material platforms, which are contained in production platforms. Furthermore, a function-based leveraging strategy was recommended to identify commonalities among product families, production processes, and raw materials as illustrated in Figure 1.

2.1 Research questions for the study

Following the previous discussion, and to close the knowledge gap, the following research questions were delineated for this study:

RQ1 Can "platform-based production and design of non-assembled products" assist in securing product variety while maintaining economies of scale and scope?

RQ2 What is the process industrial relevance and applicability of the conceptual framework and its inherent components for "platform-based design of non-assembled products"?

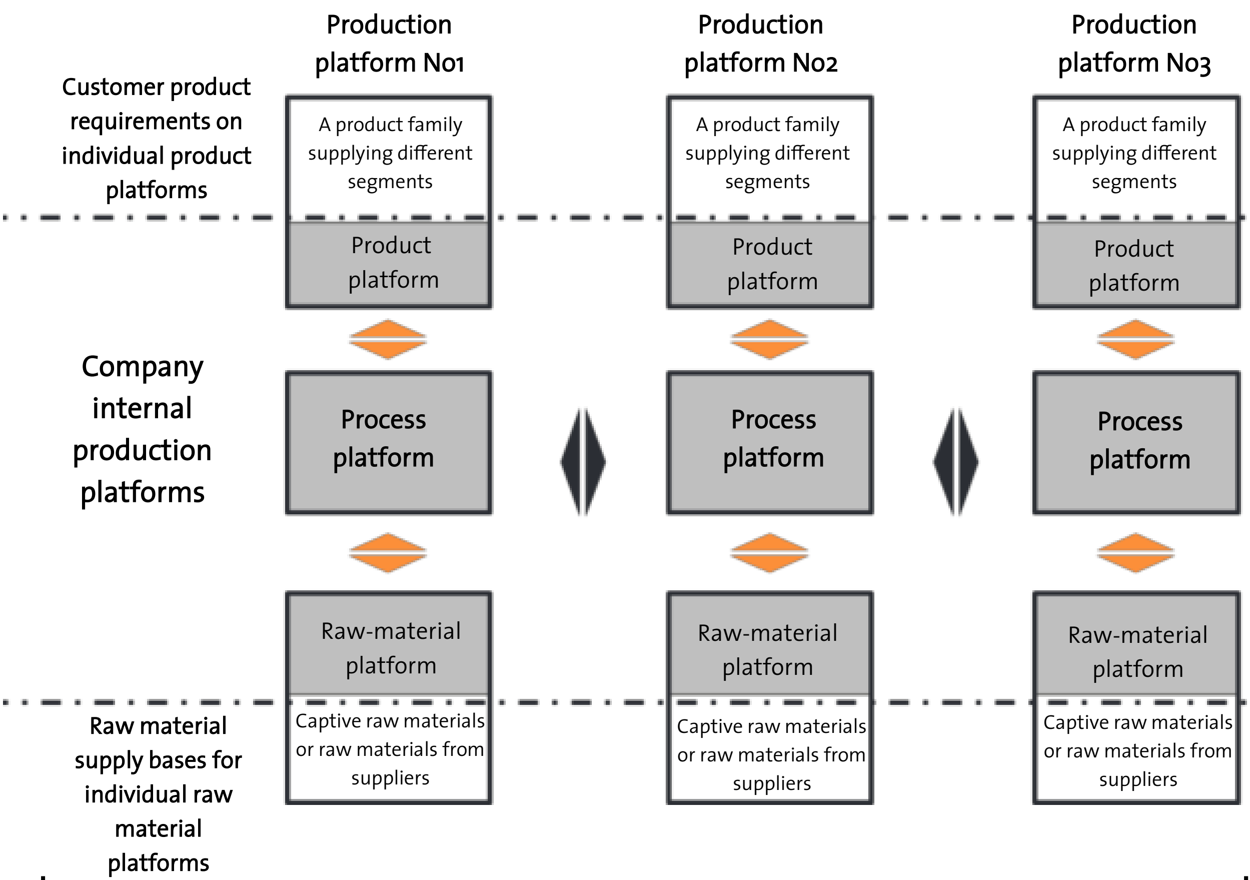
RQ3 Can the framework also be deployed as an instrument for the analysis and assessment of leveraging corporate "strategic production capabilities in a platform-based perspective"?

3 Research strategy and design

The overall research strategy for the theoretical development aimed at establishing the industrial relevance and applicability of the aforementioned conceptual framework, i.e. to inquire about the industrial "state-of-the-art" in the topical area and learn from industrial practices and inquire about the potential industrial applicability of the novel framework. To answer the research questions, a survey of Nordic process industries was selected as the research instrument. The survey was thus primarily an instrument to test and further adapt the conceptual framework to an industrial context, rather than to validate the theoretical models as such.

The use of a survey is an uncommon methodology approach in exploratory research, but in the perspective using the concept and its applicability, it was selected as a proper re-

Figure 1 Multiple production platforms (source Lager, 2017).



search instrument. The respondents were considered as "key informants" (Wagner et al., 2010):

"*Key informants report their perceptions of these constructs, rather than personal attitudes or behaviors. In this respect, informants need to be distinguished from respondents who give information about themselves as individuals.*"

In that respect, the respondents can also be viewed as "multiple informants" since their answers sometimes also related to sectoral conditions outside their own company (Wagner et al., 2010). In the effort of bridging the research-practice divide, the informants were thus asked to contribute with their answers on the numerous open questions in the inquiry, as "judges of the concept-in-use" (Barrett and Oborn, 2018).

3.1 Population of interest and the study population

Although the "population of interest" for the study is the global process industry, it was decided to include only Nordic companies from the process industries; these companies became the selected "study population". The authors' first-hand knowledge of Nordic companies in the process industries aided in the actual conduct of the survey, helped to define the study population and facilitate contact with knowledgeable respondents. The selected companies were located in Sweden, Finland, Norway and Denmark, not necessarily their registered offices, but with major production sites and R&D activities in those countries. Many are major players within their respective industry sectors, have substantial R&D activities and a minimum of 500 employees. The selected industry sectors included the mineral, forest, food and drink, chemical, metal and pharmaceutical industries. The study population was not a random sample, but rather close to being a census for some of the selected sectors of the Nordic process industries (see Table 1).

3.2 Study questionaire

The questionnaire focused on descriptive information gathering, which is an established

Table 1 Survey send-outs and responses from different sectors of the process industries in the Nordic countiers (source: own representation).

	Sweden		Finland		Norway		Denmark		Total		Total %
	Send-outs	Respon-ses	Send-outs	Respon-ses	Send-outs	Respon-ses	Send-outs	Respon-ses	Send-outs	Respon-ses	
Mineral industry	1	1	1	0	1	0	0	0	3	1	33.3%
Forest industry	6	3	4	1	1	0	0	0	11	4	36.4
Food industry	5	1	5	0	0	0	2	0	12	1	8.3%
Chemical industry	5	0	3	1	0	0	1	0	9	1	11.1
Metal industry	9	5	2	1	4	1	1	0	16	7	43.8
Pharma industry	0	0	1	0	0	0	2	0	3	0	0.0
Total	26	10	16	3	6	1	6	0	54	14	25.9
Total %	38.5		25.9		18.8		0.0		25.9		

approach when researching emerging topical areas (Yin, 1994). During the previous development of the conceptual framework, the models and related content were thoroughly reviewed and discussed, therefore a separate "pilot testing" of the final inquiry was not considered necessary. The English language was used in the questionnaires to all respondents, since English is generally well understood and often the "working language" in industrial corporations targeted in this survey. Because "platform-based design" presumably was going to be a rather new subject area for most of the respondents (informants), it was decided to gradually introduce the topical area in the questionnaire, making it a somewhat dynamic reading/answering experience for the respondents. In that respect the rather extensive and informative questionnaire was hoped to emerge as an "interview by correspondence" for the respondent.

3.3 Survey approach

After the companies had been identified, care was taken to find a respondent with intimate knowledge in the areas of product innovation and production. The company "owner" of a platform-based production and design philosophy was targeted as a Technical Director or Development Manager. A named person within each company's organization was usually contacted by telephone before the send-outs, but in a few instances the respondents were only contacted by e-mail. The questionnaires were distributed by electronic mail and the respondents could answer directly through the attached document. The questionnaire was answered by only one respondent in each company. After the send-outs, most of the respondents were reminded either by telephone call or by e-mail after about six weeks. The number of send-outs and responses are presented in Table 1. The final response rate was 25.9 % out of the total send-out of 54 questionnaires. In section 5, response-rates and a possible non-response bias are further discussed.

4 Empirical findings

In the following, each topical area in the inquiry is initially presented with the introductory statement in the questionnaire (S), and afterwards the specific question put forward (Q). The empirical results are afterwards presented as descriptive statistics, supplemented by related comments from all respondents (R). All headings in this section are identical with the questionnaire.

4.1 Securing product variety while maintaining economies of scale and scope within the firm's capabilities

4.1.1 An introduction to the problem area

(S): The need and general importance of platform-based product family design in the production of assembled products in other manufacturing industries is today unquestionable.

To compete in the marketplace, manufacturers have been seeking for expansion of their product lines and differentiation of their product offerings with the intuitively-appealing belief that large product variety may stimulate sales and generate additional revenue. Initially, variety does improve sales as the offerings become more attractive; but as variety keeps increasing, the law of diminishing returns suggests that the benefits do not keep pace. Facing such a dilemma, a company must optimize its external variety with the respect to the internal complexity resulting from product differentiation. Many companies are thus investing in product family development practices in order to provide sufficient variety to the market while maintaining the economies of scale and scope within their manufacturing capabilities.

(Q): Is the above statement relevant and an important issue also for your company (1 = Not at all; 5 = Very much so)?

(R): The respondents' answers to the question had the following statistics: mean = 4.07, std. deviation = 0.73, skewness = - 0.11.
Comments from (industry) respondents after answering this question:

- Expansion of product lines means increased complexity also for marketing and sales (forest).
- E.g., we try to use the same mixture in the "baseboard" and then vary the coating options on top of the paperboard (forest).

- Important to rationalize product lines and to have a ”leaner system” (mineral and materials).
- This is very important. We see a constant growth of new ”stock keeping units” both for our own brands and especially ”private label” brands (food and drink).
- We use the name ”attribute brands” that will consist of a number of grades but the aim is to reduce these into a smaller number of offerings (steel).

4.1.2 Company awareness of the concept

(S): In industries producing assembled products, a product platform can be defined as a set of “subsystems” and “interfaces” that form a common structure from which a stream of related products can be developed and produced efficiently, and is thus the common basis of all individual products within a product family.

(Q): Have you previously discussed the concept of “platform-based product family design” in your company as a means to economies of scale for your production capabilities of non-assembled products (1 = Never; 5 = Very often)?

(R): The respondents’ answers to the question had the following statistics: mean = 2.77, std. deviation = 1.17, skewness = 0.53. Comments from (industry) respondents after answering this question:

- We have not used the word platform (mineral).
- We do it in practice but it is not an expressed strategy or concept (forest).
- The concept is something that has been used but the terminology has been different (forest).
- I think the oil refinery industry must work this way (petrochemical).
- Yes, indirectly but not in the terms of a defined concept (steel).
- We developed this concept (without the name!!) for a long time. It is a way to optimize the mix in a product family between ”commodities” and ”specialties” (mineral and materials).
- We indirect think and act this way. Focus on upstream production and late differentiation (food and drink).
- I would say that this is what we aim for with our ”attribute brands” (steel).

4.2 Introducing a “production platform philosophy” for the process industries

4.2.1 Proposed definition of a “production platform philosophy” for non-assembled products

(S): The following introduces a proposed new “production platform philosophy for the process industries” and further to its embedded concept “platform-based design of non-assembled products”.

A platform-based production and design philosophy for non-assembled products in the process industries, involves the identification and exploitation of the shared logics and commonalities of a firm’s products, production technologies and raw materials, in order to achieve leveraged product variety and other customer offerings, while maintaining economies of scale and scope of its production capabilities.

(Q): How industrially relevant is the above definition of a “production platform philosophy” for the process industries (1 = Not useful at all; 5 = Very useful).

(R): The respondents’ answers to the question had the following statistics: mean = 4.31, std. deviation = 0.75, skewness = - 0.61. Comments from (industry) respondents after answering this question:

- Can be applied in our case for product A and product B, when processing different raw materials (mineral).
- The concept is definitely very relevant and these principles have been considered for a long time (forest).
- Offering new product solutions by combining fossil and renewable fuels, which both are produced separately in large scale is an example (petrochemical).
- This is very important (metal).
- Even if we use the same process to different products we may need to use very different process parameters and apply different knowledge and expertise to different products. Therefore, even if the definition suggested, all the economies of scale may not be maintained (steel).

- We need to sell our products based on added value for the customer. Therefore we need to identify what properties we can differentiate our product with compared to competitors. Making each or a combination into a platform is a way of explaining this (steel).

4.2.2 Modelling the structural components of a single production platform

(S): The structural components of a production platform is thus proposed to include a well -integrated product platform, process platform and raw material platform producing a family of derivate products, supplying different market segments and relying on a selected captive or/and supplied raw material base (reference to a figure identical to Figure 1 in the present paper).

- The development of a product platform relies on the identification of commonalities and shared logics of customers' present and future product requirements and their translations into well-defined and measurable product design requirements and functionalities.
- The development of a process platform relies on the identification of commonalities and shared process logics of present and future production technologies and unit process architectures for the production of the related product platform.
- The development of a raw material platform relies on the identification of commonalities and shared raw materials and supply chain logics of present and future raw materials and specifications for the related process platform.

(Q): How useful is the above conceptual model of a "production platform" and its embedded platform components for non-assembled products for an application in your company (1 = Not useful at all; 5 = Very useful)?

(R): The respondents' answers to the question had the following statistics: mean = 4.07, std. deviation = 0.73, skewness = - 0.11. Comments from (industry) respondents after answering this question:

- I think it will visualize in a better way the need for processes that are adapted to both raw materials and type of product (mineral).
- The concept is at least partly applied though not defined in line with above (forest).
- To become relevant in the real-world portfolio development there is a need to have proper tools for defining each platform clearly (forest).
- It is quite generic but describes the platform well (petrochemical).
- This is more or less how we work (steel).
- I think we utilize similar thinking already now. I am not sure if such a model would create added value (steel).

4.2.3 Modelling multiple production platforms

(S): A number of production platforms can be identified on an individual production site but could also be stand-alone platforms in a geographically global perspective (Figure 1).

(Q): Could your company's present production situation be translated into the presented model structure in Figure 1 (1 = Not at all; 5 = Very much so)?

(R): The respondents' answers had the following statistics: mean = 4.00, std. deviation = 0.96, skewness = - 0.61. Comments from (industry) respondents after answering this question:

- The main added value in your definition is to demonstrate the links between the three platforms since too often there is an optimization only by one platform (mineral and material).
- Process platforms in my kind of industry could to some extent be linked between production units but not to the full extent (forest).
- Each site may have a different platform but we can also have different platforms (processes) within a site (steel).
- Yes, more generally with some customers you need to have this (mineral and material).
- The figure describes the situation well. In our terminology, the production plat-

forms are production lines at a particular site (petrochemical).

- Yes, but some of our geographically diversified mills only have a very limited platform structure in itself (forest).

4.3 Platform-based design of non-assembled products in the process industries

4.3.1 A proposed product "function-based" leveraging strategy for the development of product platforms

(S): Because products manufactured in the process industries often have a number of well-defined functional properties (attributes), the following definition of a product "function-based" leveraging strategy for platform-based design of non-assembled products is therefore proposed:

After all individual customer requirements for a product family are identified, and their importance ratings within all selected different market segments are assessed, these importance ratings must afterwards be recalculated into importance ratings of all product design requirements for each individual market segment. A "function-based" product leveraging strategy for platform-based design of non-assembled products is then setting target figures for the conceptual development of each product variety, based on the variability of each individual design requirement and commonalities of functional properties within the product family.

(Q): How industrially useful is the definition of a product "function-based" leveraging strategy presented below for non-assembled products (1 = Not useful at all; 5 = Very useful)?

(R): The respondents' answers to the question had the following statistics: mean = 3.50, std. deviation = 1.16, skewness = 0.17. Comments from (industry) respondents after answering this question:

- Although the content as such seems OK, this sounds too complex for being used for communicating the concept (petrochemical).
- We are working in this direction (steel).
- Yes, extremely useful and time to time not so easy to implement. Nevertheless, it is clearly a very good proposal (mineral and material).
- Seems to be a quite theoretical approach not so easy to understand (steel).
- Some functional properties exist, which you could in theory use for developing new future product strategies (forest).

4.3.2 A proposed leveraging strategy for the development of process platforms

(S): (Selected part of introductory statement) In the identification of process platforms, the process technology configuration is a suitable starting point and that the leveraging strategy for process platform identification could be the use of similar unit processes in the total production system. A process platform in the process industries can thus be the foundation for derivate production structures and set-ups that can be termed "process architectures". Such a family of production processes is then based on production technology commonalities and shared process-logics.

(Q): From your general industrial process knowledge and the experiences from your own industrial sector, is the leveraging strategy for process platforms relevant (1 = Not useful at all; 5 = Very useful)?

(R): The respondents' answers had the following statistics: mean = 3.79, std. deviation = 0.98, skewness = -0.09. Comments from (industry) respondents after answering this question:

- This is very dependent on how easy one can switch between different platforms (mineral).
- Standardizing of processes is a key success factor to develop operational excellence. When a transfer is necessary between one platform to another, you save time (material and mineral).
- We have today separate platforms for producing fossil and renewable products (petrochemical).
- Yes, it is somewhat relevant in that we could use this way of thinking when setting up a new product line (steel).
- Pretty natural (food and drink).

- Should the same product be sorted into several families or does it make sense to create a new family comprising the properties of many of the other? (steel).

4.3.3 Alternative scenarios for process platform development

(S): Depending on necessary process technology for existing, improved or completely new production platforms, the following technology scenarios are identified. Which of these scenarios is most relevant for your company's present situation?

1) The company process platform can rely on existing production technology at the production site. (This scenario was applicable for 3 respondents.

2) The company process platform will need complementary purchased production technology. (This scenario was applicable for 4 respondents.)

3) The company process platform needs in-house development of new production technology. (This scenario was applicable for 3 respondents.)

(Q): From your general industrial process knowledge and the experiences from your own industrial sector, are the above scenarios relevant (1 = Not at all; 5 = Very much so)?

(R): The respondents' answers had the following statistics: mean = 4.36, std. deviation = 0.93, skewness = -1.53. Comments from (industry) respondents after answering this question:

- For all our products we can use existing technology but we need in-house development for the adaption to different and new raw materials (mineral).
- Process platform development strategy is not explicitly expressed (forest).
- In-house development of new production technology is nowadays very uncommon (high cost and risk) (forest).
- The tendency in the industry is to opt for reduced product portfolio and a higher applicability of each product to a wider spectrum of application areas. Under these circumstances the tendency is to build production platforms that can embed multiple capabilities into one product rather than variation of products themselves. This has a higher impact on the modularity of a process platform (forest).
- Existing technology shall be leveraged without sacrificing the need for further development, either in-house or with partners. (petrochemical).
- We have the whole spectra: 1) For bulk standard products 3) for "special products," Scenarios 1-2 are most common. Own engineering for "special products" to a smaller degree (food and drink).
- I would say that all scenarios are relevant. For the more mature products we may use existing production structure (scenario 1). For products in the development phase, scenario 2. For products in on-going research, it can be scenario 3 (steel).

4.3.4 A proposed leveraging strategy for the development of raw material platforms

(S): (Selected part of introductory statement) Platform-based design of non-assembled products may differ and which of the below scenarios is most relevant for your company present situation?

1) Company production solely relies on a captive (company-owned) raw material base. In this scenario, the quality of available raw materials will ultimately determine the products and product families that could be produced and supplied to different market segments. This requires an iterative matching of customer needs, process capabilities and available raw material qualities in the development of different Production platforms. (This scenario was applicable for 3 respondents.)

2) Company production solely relies on purchased raw materials on the open market. In this scenario, the product platforms that are responsive to customer and market needs must naturally be the point of departure for the development of existing or new production platforms. (This scenario was applicable for 2 respondents.)

3) Company production partly relies on a captive raw material base and purchased raw materials. In this scenario, the available captive raw material base must be considered together

with optional purchased raw materials on the open market and matched with available or new production technology and market needs in the development of production platforms. (This scenario was applicable for 6 respondents.

(Q): From your general industrial process knowledge and the experiences from your own industrial sector, are the above scenarios relevant for a leveraging strategy for the development of raw material platforms? (1 = Not at all, 5 = Very much so)?

(R): The respondents' answers had the following statistics: mean = 3.86, std. deviation = 1.10, skewness = -0.49. Comments from (industry) respondents after answering this question:

- For some purchased raw materials, the number of suppliers is very limited (forest).
- This is the "bread and butter" skill of product development practice. How to maintain tolerable product efficiency with the variations of raw materials is a key to profitable operations (forest).
- Complex situation, since the "captive" raw materials also can be purchased (forest).
- We may compensate for some variations in the purchased material but only up to a point (steel).
- The supplier is often specified by our customer, and it is difficult to change supplier (steel).

4.4 A final assessment of the proposed concepts and models

(Q): In a final appraisal of "platform-based design" of non-assembled products, could the presented philosophy and models be of interest for your company (1 = Not really; 5 = Most likely)?

(R): The respondents' answers to the question had the following statistics: mean = 4.07, std. deviation = 0.73, skewness = -0.11. Comments from (industry) respondents after answering this question:

- I think the concept will help in visualizing how new product development is related to both processing of raw material and the process development different raw materials needs (mineral).
- The bigger the company is with many production sites, producing similar or almost similar products, with fairly similar technologies, this would be of a very high interest (forest).
- The underlying need for platform-based design is of course very relevant (forest).
- Some of it is already in use; some areas could be further developed in a more systematic way (petrochemical).
- Due to the complex nature of our raw materials, processes and products, it is likely that the proposed concepts might be oversimplified and thus not useful (steel).
- Time to time, it looks too "simple" but in fact it is a very good way to re-question our methodologies and strategies (mineral and material).
- We could certainly benefit from thinking along these lines (food and drink).
- The concept as such could be useful, but it must be simplified as how it is presented (forest).

5 Discussion

5.1 A discussion of empirical findings

The inquiry touched upon an important strategic area for many companies; the respondents' comments were insightful and provided rich, positive feedback, thus stimulating the further development of the conceptual framework. Kumar et al. (1993) elaborate the key informant concept as:

"*Researchers do not select informants to be representative of the members of a studied organization in any statistical sense. Rather, they are chosen because they are supposedly knowledgeable about the issue being researched and able and willing to communicate about them.*"

The information obtained from the respondents proved to be most valuable for the forthcoming development and industrialization of the framework.

5.1.1 On securing product variety and company use of a "platform concept"

The initial findings presented in 4.1.1 indicate that securing product variety while maintaining economies of scale and scope within company manufacturing is considered to be a most important goal in the process industries (mean value 4.1), but one that is somewhat difficult to achieve. The inquiry focused on the relation between the production system and product variety, but one respondent remarked that expansion of product lines also introduces an increased complexity for marketing and sales. Comments from one respondent that supply chain complexity is strongly affected by high product variety underscoring the importance of a company "end-to-end" approach in product innovation, and to consider supply chain complexity (Dittfeld et al., 2018).

In reference to company use of a "platform concept" in 4.1.2, some companies expressed that they "do this in practice" or "we indirect think and act this way", but it is not articulated as an innovation concept or an overall company production strategy. Others responded that "platform-based product family design" is something they aim for, trying to develop operational structures into a more "platform-like mode", even if the term "platform" is never used. However, this behavior and practice is generally not well defined and is not an operational approach that could be described as a "platform-based product philosophy". Referring to Ludwig Wittgenstein's (Wittgenstein, 1921) statement that "Wovon man nicht sprechen kann, darüber muss man schweigen" ("What you cannot talk about, you have to be silent about"), lacking well-defined concepts and articulated development strategies; advanced and enhanced practices are difficult to discuss, communicate and consolidate in organizations.

5.1.2 On the definition of a "production platform philosophy" and the conceptual modelling of production platforms

The integration of raw materials, production technology, and products in the definition of a "platform-based production and design philosophy" in 4.2.1 was considered to be most relevant, and it was rated very high (mean value 4.3). The simplified conceptual model in Figure 1 was considered a key feature in the proposed framework, see 4.2.2. One respondent expressed that: "it will visualize in a better way the need for processes that are adapted to both raw materials and type of product". In 4.2.3, the opportunity to integrate "multiple production platforms", presented in Figure 1, was rated very high. The possibility to link individual platforms in an overall framework was also recognized to "avoid optimization only by one platform". It was commented that each production site could contain several platforms, but possible linkages in-between platforms in a multiple site perspective is interesting.

5.1.3 Managing operational constraints

The results on the process platform leveraging strategy in 4.3.2, and the underlying thought was well received (mean value 3.8), and the proposed "unit process" approach was considered to be relevant or even "natural". Standardization of process platforms was noted as an important issue. In 4.3.3, the three different scenarios for the development of raw material platforms were generally regarded relevant. One respondent expressed this as "This is the bread and butter skill of product development practice. How to maintain tolerable product efficiency with the variations of raw material is the key to profitable operations".

Even after a brief presentation of the concept of integrated knowledge platforms, the respondents probably intuitively recognized that this concept could be of interest in future product innovation (see 4.4.2). One respondent stated that "Integrated knowledge along the whole value chain from raw materials to end products is a key for successful innovation." Finally, in reference to 4.4.3, the overall industrial interest to further explore the conceptual framework in the respondents' own company was rated high (mean value 4.1). Overall the comments were generally supportive and sometimes enthusiastic to the potential applicability of the proposed ideas and the presented framework.

5.2 Research limitations and a discussion of the non-response rate

A consequence of a low response-rate is not only that the sample size is reduced, but that the non-responding companies may represent a select group that could give biased results. There are three major causes of a non-response: no contact, a refusal to answer, or not being able to answer. In this survey the non

-response rate is primarily a result of no contact and a refusal to answer. Six potential respondents declared that they declined to answer, excusing themselves for lack of time for answering surveys of this complexity. The zero response rate for companies in Denmark is somewhat surprising, but considering the topical area for the survey, one can argue that the reason for zero response was not dependent on a different perspective on "platform-based design" compared to companies in the other Nordic countries.

Referring to Table 1, the response rate differed substantially among the Nordic countries. The Swedish figure of 38.5 % and the Finnish figure of 25.9 % are response rates not uncommon in today's difficult "industrial climate for management surveys". The overall response rate could also possibly be related to the new, and for many respondents somewhat difficult, topical area for the inquiry. Some comments from the respondents indicate that the questionnaire was rather difficult to comprehend, while some respondents on the other hand praised the intellectually challenging models and the stimulating content. The response rate from different industrial sectors differ substantially and the highest response rate from the metal industry (43.0%) is acceptable, while the zero response rate from the pharmaceutical industry is not. The differences may not only be related to difficulties to get answers but could possibly be biased by how applicable the conceptual framework is for different sectors of the process industries.

5.3 Major findings and theoretical contribution

One criterion of "good research" is how usable the research results are. This question is further stressed in the presentation of "grounded theory" where the pragmatic criterion of truth is its usability (Glaser and Strauss, 1967). Related to this philosophical standpoint, Whetten (1989) and Corley and Gioia (Corley and Gioia, 2011) cogently defined "theoretical contribution" as the ability to produce thinking that is original in its insight and useful in its application. When it comes to the notion of "originality," a theoretical contribution can be categorized as either advancing understanding incrementally or in a more revelatory or surprising manner (Corley and Gioia, 2011). On the practical utility, Corley and Gioia suggest "prescriptions for structuring and organizing around a phenomenon." The authors of the present study also suggest that the practical utility has two main dimensions: the findings themselves and the form in which the research can be disseminated to practitioners.

In the perspective of both comments from the respondents on the specific questions as well as from the analysis of the empirical data, two rather different but strongly related major findings emerge and constitute the theoretical contributions from this study. First, in the previously presented conceptual framework which was deployed as the research instrument it is initially proposed that it could be used in "platform-based design of non-assembled products" (Lager, 2017). The results from this study indicate not only the industrial need for well delineated frameworks and models, but also that the conceptual model can serve such a purpose. In that respect, the empirical results from the survey advances the scientific position since, in reference to Corley and Gioia (2011), it "improves conceptual rigor or the specificity of an idea and/or enhances its potential to be operationalized and tested." Second, the results from this study additionally indicate that the conceptual framework could be deployed to review and assess corporate strategic production capabilities. In the perspective of these new findings, it is thus proposed that all product families, including all product varieties, should be contained in the following activities:

- Identify and delineate company site specific production platform architectures, and their embedded product-, process- and raw material platforms.
- Investigate and assess the capabilities of each individual platform architecture and its embedded components from the prospect of product variety, flexibility, operational efficiency, process integration and raw material supply conditions.

In consideration of the "utility" aspect, it is argued that the framework is providing industry professionals an instrument for "structuring around a phenomenon"; the area investigated in this study. Moreover, in the overall perspective of "practical utility", the framework has proved to be an excellent communication tool with industry practitioners. A tool not only for discussions of platform-based product design but also as a guiding framework for an analysis of corporate strategic production capabilities. It is argued that the results from this study thus fulfil the criterion for a theoretical contribution since the results have originality and the utility is high for both academics and practitioners.

6 Managerial implications

In view of the encouraging results from this exploratory study, it is suggested that the conceptual framework already can serve as a "theoretical coat hanger"; a point of departure for introducing and developing a platform-based production philosophy and a platform-based design of non-assembled products in the process industries. Moreover, using the conceptual framework in the development and design of non-assemble products and product varieties could be one avenue to follow in managing product variety under operational constraints.

7 Conclusions

The low response rate from some industry sectors makes it difficult to draw any firm conclusions on present use of "platform-based design of non-assembled products" in the process industries in general, but in answering the first research question, it is indicated that this is a new conceptual idea within this family of industries. The initial finding from the study confirms that all respondents struggle with the problem area and how to improve management of product variety under operational constraints. The results also indicate that the new ideas and models were much in-line with current industrial mental models, but the holistic perspective and new constructs on "platform-based production and product design" also challenged the respondents' present company paradigms and working practices.

Related to the second research question, the overall findings from the survey acknowledged the applicability of many components of the proposed framework, and the need for a well-delineated and more pronounced "platform-based production and product design philosophy" for process-industrial use. The results from this survey will thus be integrated and used in the further development of the framework, making it a clearer, more coherent, and also more digestible for industry professionals.

In reference to the third research question, the industrial relevance and acknowledged applicability of the conceptual framework in this study suggests that it can be deployed both as an instrument for an analysis of companies' present production systems and similar product innovation practices, and for company implementation and deployment of the novel framework. It is finally advocated that both kinds of industrial use could be amalgamated, embedded, denominated and industrially deployed as an overall "platform-based philosophy for production and design of non-assembled products.

To the authors' best knowledge, academic and professional publications in the area of industrial use of platform-based design and production of non-assembled products is scarce. Apart from the conceptual framework deployed in this study, it is argued that the findings from this study thus fulfill the criteria for a theoretical contribution because the results have originality and high utility for both academics and practitioners.

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References

Barrett, M. and Oborn, E. (2018): Bridging the research-practice divide: Harnessing expertise collaboration in making wider set ofcontributions. *Information and Organization*, **28**, p. 44-51.

Belt, A., von Hagel, K. and Ferguson, S. (2015): Navigating redesign and market desirability implications when considering product variety, *Journal of Engineering Design*, **26**, p. 236-258.

Corley, K. G. and Gioia, D. A. (2011): Building theory about theory building: What constitutes a theoretical contribution, *Academy of Management Review*, **36**, p. 12-32.

Daie, P. and Li, S. (2016): Managing product variety through configuration of pre-assembled vanilla boxes using hierarchical clustering, *In-*

ternational Journal of Production Research, **54**, p. 5468-5479.

Dittfeld, H., Scholten, K. and van Donk, D. P. (2018): Burden or blessing in disguise: interactions in supply chain complexity, *International Journal of Operations and Production Management*, **38**, p. 314-332.

Flapper, S. D. P., Fransoo, J. C., Broekmeulen, R. A. C. M. and Inderfurth, K. (2002): Planning and control of rework in the process industries: a review, *Production Planning and Control*, **13**, p. 26-34.

Frishammar, J., Lichtenthaler, U. and Kurkkio, M. (2012): The front end in non-assembled product development: a multiple case study of mineral- and metal firms, *Journal of Engineering and Technology Management (JET-M)*, **29**, p. 468-488.

Glaser, B. G. and Strauss, A. L. (1967): *The dicovery of grounded theory: strategies for qualitative research*, New York, Aldine de Gruyter.

Halman, J. I., Hofer, A. P. and van Vuuren, W. (2003): Platform-Driven Development of Product Families: Linking Theory with Practice, *Journal of Product Innovation Management*, **20**, p. 149-162.

Jack, E. and Raturi, A. S. (2003): Measuring and comparing volume flexibility in the capital goods industry, *Production and Operations Management*, **12**, p. 480-501.

Jianxin, J., Simpson, T. W. and Siddique, Z. (2007): Product family design and platform-based product development: a state-of-the-art review, *Journal of Intelligent Manufacturing*, **18**, p. 5-29.

Kahn, B. E. (1998): Dynamic Relationships With Customers: High-Variety Strategies, *Journal of the Academy of Marketing Sciences*, **26**, p. 45-53.

Kumar, N., Stern, L. W. and Anderson, J. C. (1993): Conducting Interorganizational Research Using Key Informants, *Academy of Management Journal*, **36**, p. 1633-1651.

Lager, T. (2017): A conceptual framework for platform-based design of non-assembled products, *Technovation*, **68**, p. 20-34.

Luo, X., Tang, J. and Kwong, C. (2010): A QFD-based optimization method for a scalable product platform, *Engineering optimization*, **42**, p. 141-156.

Meyer, M. H. and Dalal, D. (2002): Managing platform architectures and manufacturing processes for nonassembled products, *Journal of Product Innovation Management*, **19**, p. 277-293.

Meyer, M. H. and Lehnerd, A. P. (1997): *The Pover of Product Platforms: Building Value and Cost Leadership*, New York, The Free Press.

Park, J., Shin, D., Isun, P. and Hyemi, H. (2008): A product platform concept development method, *Journal of Engineering Design*, **19**, p. 515-532.

Robertson, D. and Ulrich, K. (1998): Planning for Product Platforms, *MIT Sloan Management Review*, **Summer 1998**.

Samuelsson, P., Storm, P. and Lager, T. (2016): Profiling company-generic production capabilities in the process industries and strategic implications, *Journal of Manufacturing Technology Management*, **27**, p. 662-691.

Suh, N. P. (2001). *Axiomatic design: Advances and applications*, New York, Oxford University Press.

Wagner, S. M., Rau, C. and Lindeman, E. (2010): Multiple Informant Methodology: A Critical Review and Recommendations, *Sociological Methods and Research*, **38**, p. 582-618.

Van Campen, T. and van Donk, D. P. (2014): Coping with product variety in the food processing industry: the effect of form postponement, *International Journal of Production Research*, 52, p. 353-367.

Whetten, D. A. (1989): What Constitutes a Theoretical Contribution? *Academy of Management Review*, **14**, p. 490-495.

Wilson, S. and Ali, N. (2014): Product wheels to achieve mix flexibility in process industries, *Journal of Manufacturing Technology Management*, **25**, p. 371-392.

Wittgenstein, L. (1921): *Tractatus Logico-philosophicus*, New York, Dover Publications Inc.

Yin, R. K. (1994): *Case Study Research; Design and Methods*, Thousand Oaks, Sage Publications.

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