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Letter from the Editors

One year COVID-19

Although no reason to celebrate, the pandemic's influence cannot be denied and does not leave the chemical and related industries untouched. The pandemic also influenced the topics addressed in the first Journal of Business Chemistry issue 2021, albeit in different ways: The fifth session of the International Conference on Chemicals Management (ICCM5) set to discuss the Strategic Approach to International Chemicals Management (SAICM) beyond 2020 was postponed while digitalization was sped up and with the exponentially growing amount of created data the importance of data science techniques increases likewise. COVID-19 replaced climate topics in the news but sustainability is far from being forgotten and decisions like the European Green Deal raise hope for a green recovery and transformation.

Graham Gibson´s article "The Strategic Approach to International Chemicals Management: A Case Study of Transnational Public-Private Partnerships in the Chemicals Sector" explores the strengths and weaknesses in the approach chosen in the SAICM. The results indicate that setting precise goals and establishing a connection to the Sustainable Development Goals (SDGs) are two important points to consider in future agreements.

In "When data science meets patent information – analyzing complex environments of innovation-driven industries" Anton Block, Jan Hendrik Konhäuser, Jonas Meyerratken, Christiane Terlinde and Philipp Niklas Voß show how data-driven patent analysis can support management decision. They present four examples of use based on different data-mining techniques from the fields of antibiotics, stem cells, lithium-based batteries and personalized medicine.

In "Reducing the emissions scope 1-3 in the chemical industry" Manfred Kircher discusses what needs to be done to move towards a truly climate-neutral chemical industry. He emphasizes that next to the energy related scope 1&2 emissions, scope 3 emissions need to be urgently reduced. Five options to reduce the emission potential by recycling and the use of non-fossil carbon are presented, namely biomass, recycling of residual and waste materials, plastic recycling and both carbon dioxide and carbon monoxide as carbon sources.

Please enjoy reading the first issue of the eighteenth 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.
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Commentary

Manfred Kircher*

Reducing the emissions Scope 1-3 in the chemical industry

1 Introduction

Since the European Emissions Trading Scheme (ETS) was installed in 2005, the operators of more than 11,000 emissions-intensive plants, including many in the chemical industry, have had to buy so-called emissions allowances for the release of their emissions. A central control instrument of the trading system is that the number of allowances is continuously reduced, i.e. the overall volume of emissions is capped. While the number of allowances was reduced by 1.7% per year in the 3rd trading period from 2013-2020, the reduction rate will accelerate to 2.2% in the 4th trading period from 2021. At the same time, the number of industries that will receive mitigating special rules to avoid the migration of these emission sources from the EU (carbon leakage regulations) will be reduced. From 2021, the manufacture of plant protection products, personal care products and pharmaceutical specialties, to name but a few, will no longer be specifically spared (EC, 2020; VCI, 2020).

Allowances are freely tradable; their market price has increased by a factor of six since the start of the ETS to EUR 32 per metric ton of carbon dioxide equivalent today, and a further increase is expected. Model calculations for the German chemical industry up to the year 2050 were based on an assumed price for allowances of EUR 100 per ton of carbon dioxide in 2050 (Dechema and FutureCamp, 2019). The ETS has already burdened the German chemical industry with EUR 1.34 billion annually in the 3rd trading period alone.

In terms of emissions reduction, the trading system has been and continues to be quite successful. Since 1990, emissions from the European chemical industry covered by the ETS have fallen by 58% to 135 million metric tons of CO_2-equ. These are in particular the emissions arising from energy production (CEFIC, 2020). The sectors covered not only achieved the reduction target set for 2020, but actually fell short of it. The energy sector in particular contributed to this. The pressure on the other sectors involved to reduce emissions, including the chemical industry, will therefore tend to increase further, especially as climate change is accelerating despite global climate protection measures. Global warming of 1.5°C can no longer be ruled out as early as 2024, and there are therefore voices that believe a radical reduction in greenhouse gas emissions worldwide is necessary by 2030 (IPCC, 2018). In the near future, therefore, it cannot be ruled out that the political framework for reducing emissions will be tightened more drastically than previously planned. Industry would therefore be well advised to consider prophylactic options for action. So where could further measures be taken within the framework of the emissions trading system, which is in itself a successful concept? To address this question, the different emission sources and how the ETS treats them need to be considered (Fig. 1). A distinction is made between emissions generated by a company itself from its own facilities (Scope 1), emissions attributable to purchased energy (Scope 2) and emissions originating from purchased raw materials and the use or disposal of sold products (these are the largest sources of emissions; in fact, emissions are recorded in much greater detail).

2 Scope 1 and 2 emissions

First, the existing strategy of capping energy-related Scope 1 and 2 emissions and making the corresponding allowances more expensive could be further intensified. This would increase the already existing pressure to reduce energy-related emission sources. In principle, there are three options for doing this, namely 1. using emission-free energy,

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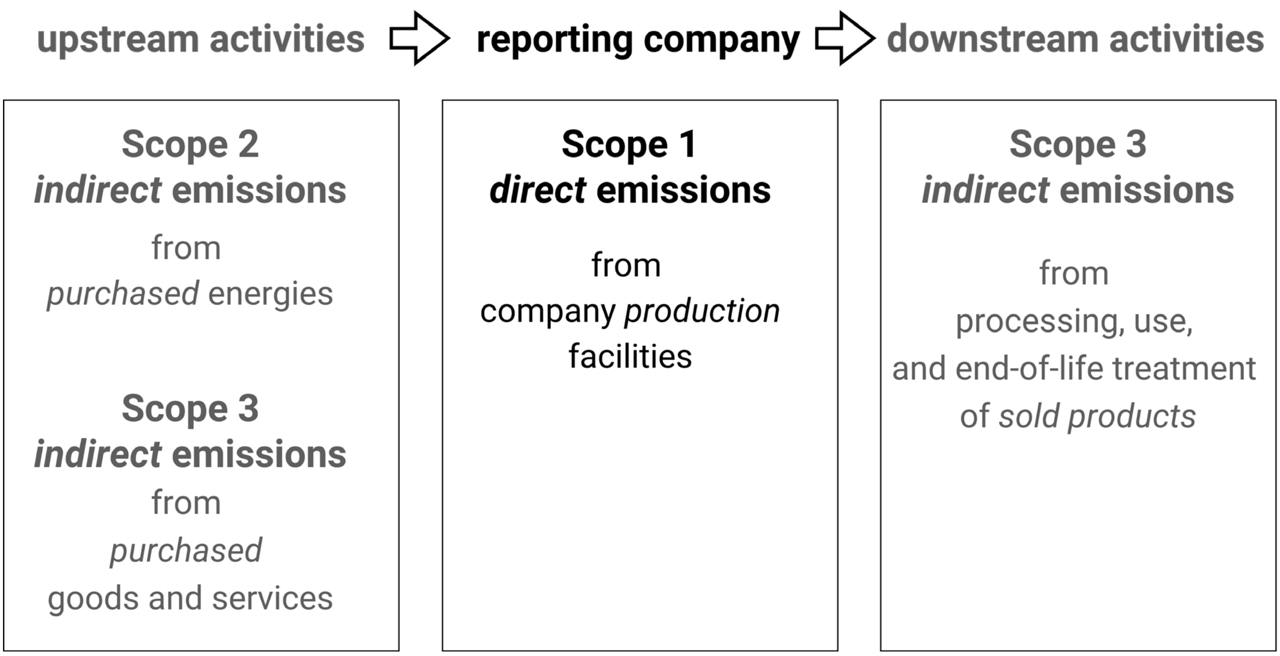

Figure 1 Simplified classification of Scope 1-3 emissions (own representation).

2. switching to emission-free processes, and 3. capturing CO_2 from emission gases:

1. Many companies are focusing on the use of emission-free energies. For example, companies such as Bayer and Henkel have published plans to reduce their carbon footprint, particularly with the help of renewable energies (Bayer, 2019; Henkel, 2021). Special attention is paid to the largest source of emissions in the chemical industry, namely steam cracking, which accounts for 26%. The use of renewable energies could significantly reduce this emission source (Amghizar, et al., 2020).

2. It is not only the switch to emission-free energies that increases the climate compatibility of chemistry. The use of processes that replace fossil carbon sources with electricity can also reduce emissions. One example is the production of ammonia, which, with the processing of natural gas, now accounts for 39% of chemical emissions (2017) (CEFIC, 2020). The alternative process of solid state ammonia synthesis (SSAS), on the other hand, combines the electrolytic production of hydrogen and the Haber-Bosch synthesis into an integrated emission-free process (Holbrook and Leighty, 2009). However, processes that consume electricity and hydrogen are extremely energy-intensive. They will greatly increase the demand for emission-free energy from the chemical industry. Their introduction therefore depends on the provision of the corresponding capacities by the energy sector. Today, the European chemical industry consumes for energy purposes around 52.7 million tonnes of oil equivalent (toe) in total, of which 13% is renewable energy and biofuels (2017) (CEFIC, 2020).

3. Alternatively, carbon capture and storage (CCS) offers an option for avoiding the emission of greenhouse gases into the atmosphere. In Europe, however, this process has so far only been used in Norway for the extraction of natural gas and has met with a lack of social acceptance in many countries (Cuéllar-Franca and Azapagic, 2015).

3 Scope 3 emissions

As part of the tightening of the EU emissions trading system, Scope 3 emissions, which have not yet been taken into account, could also be included. Although Scope 3 emissions are reported as part of the CSR (corporate social responsibility) reports, they are not subject to the emissions trading system.

Scope 3 includes all emissions attributable to purchased materials and services as well as to the further processing,

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use and disposal of sold products. Scope 3 categories 1 and 12 account for the most significant share of these emissions. Category 1 includes emissions from the purchase of chemical raw materials, packaging materials, and indirect goods. Among the raw materials of the chemical industry, fossil carbon sources account for 90% (petroleum 74%, natural gas 15%, coal 1%, biogenic 10%; EU, 2015) (CEFIC, 2016). This emission potential purchased from the supply chain is often referred to as the carbon backpack. Category 12, on the other hand, contains the emissions released during the disposal and recycling of products. In other words, this emission potential corresponds to the volume of carbon dioxide that can be released from organic chemical products during incineration. An order of magnitude can be estimated from the volume of fossil raw materials used as a carbon source of 74,717 million toe (EU, 2013) (Boulamanti and Moya, 2017). Assuming an average carbon content of 80% and accumulated process losses of 30%, the resulting products would have a potential for carbon dioxide emissions of around 150 million tons, i.e. in the order of magnitude of the Scope 1 and 2 emissions mentioned above. This corresponds to the ratio of Scope 1, 2 and 3 emissions to each other reported for the German chemical industry (Dechema and FutureCamp, 2019).

Basically, there are five options to reduce this emission potential by recycling and using non-fossil carbon sources (Fig. 2):

1. Biomass: Biomass from agricultural and forestry products as well as from marine sources is considered an emission-neutral carbon source because the carbon bound in the biomass has been removed from the atmosphere in the course of the natural carbon cycle. The source of energy is the sun. Accordingly, bio-based products are basically considered to be climate neutral. Today, 10% of the carbon sources for the chemical industry are based on biomass. Examples of industrial practice are bio-based acrylic acid (Bio-based News, 2012) and polyurethan elastomers (European Plastic Product Manufacturer, 2020). However, limitations to the large-scale use of primary biomass must not go unmentioned. The production of biomass for industrial applications competes with land use for food, which is given priority in the general consensus of society. In addition, agricultural production of biomass also generates greenhouse gases. Its share of total European emissions is 10% (2015) (EC, 2017) and could be increased by intensifying agriculture for industrial purposes. An

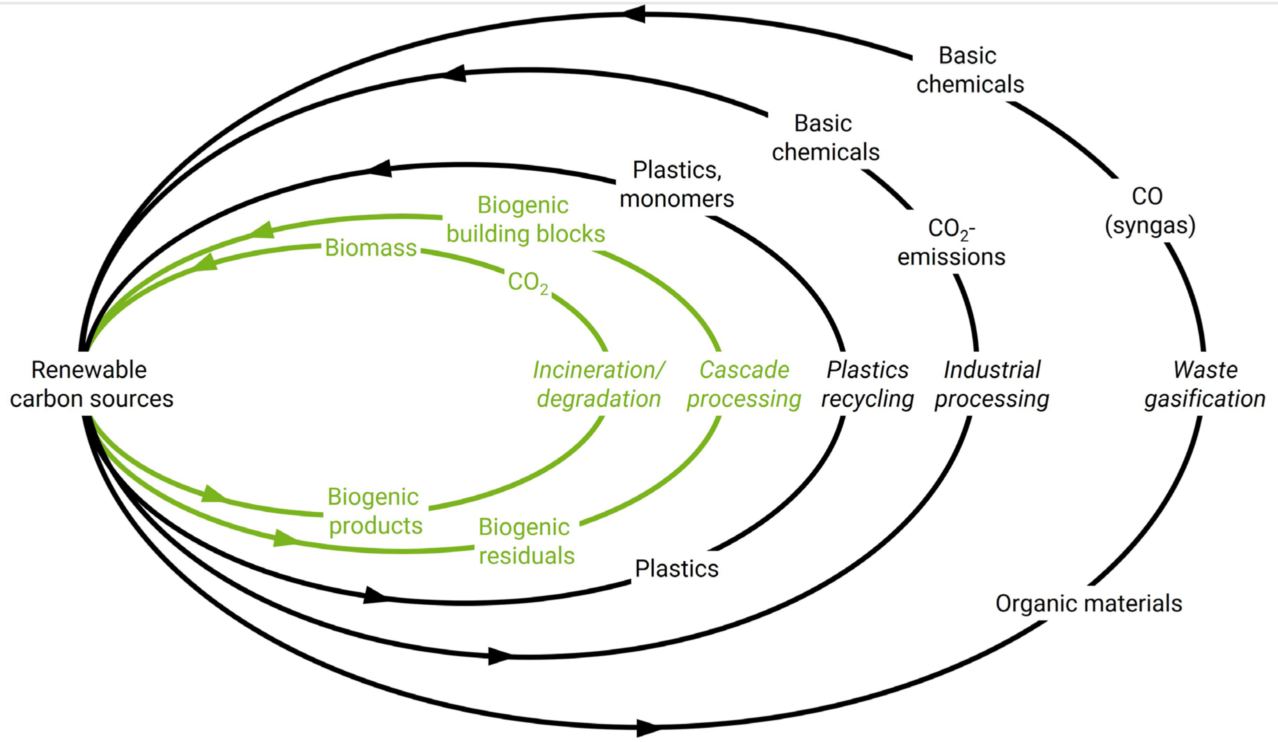

Figure 2 Options for renewable carbon sources: biomass, biogenic residuals, plastics recycling, CO_2 and CO; green: biogenic carbon; black: any carbon (own representation).

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increased use of agriculture as a raw material supplier for the chemical industry is also limited by already partly damaged planetary boundaries (PIK, 2019).

2. Recycling of residual and waste materials: Agricultural and forestry waste (straw, residual wood), as well as residual and waste materials in densely populated and industrialized metropolitan areas (industrial residues, food waste, green waste, sewage sludge) have raw material potential for industrial processes in the context of cascade utilization. Straw for example is already used for the production of bio-ethanol (Clariant, 2020). Because the above-mentioned raw materials occur seasonally and with varying composition, they need to be standardized into a raw material that meets specifications. Biogas can play a key role in this field, because a large proportion of the waste and residual materials mentioned can be fermented anaerobically to form biogas and thus supply (bio)methane as a chemical raw material. Biogas fermentation of waste is state of the art. The microorganisms of the biogas fermentation obtain the energy required for the conversion from the raw materials.

3. Plastic recycling: In Europe, 39% of plastic waste is incinerated, 31% landfilled and only 30% recycled (EU-Parliament, 2018). The European Commission asks for creating the capacity to recycle 55% of packaging plastics in the EU by 2030 (EC, 2018).

4. Carbon dioxide: Carbon dioxide from industrial point sources of both fossil-based and bio-based processes (combustion, fermentation) can be used as a carbon source. Algae can photosynthetically metabolize carbon dioxide, but are costly to cultivate. Bacteria can produce more easily in steel boilers, but require hydrogen to reduce carbon dioxide. A corresponding process for butanol and hexanol will reach the pilot phase in 2021 (Evonik, 2020). Chemo-catalytic processes are already established. For example, Covestro produces polyols starting from carbon dioxide (Covestro, 2020). In the long term, carbon dioxide is even seen as having the potential to establish itself as a dominant raw material (Dechema and FutureCamp, 2019; nova-institute, 2020). A prerequisite is the development of sufficient emission-free energy capacities for the provision of hydrogen.

5. Carbon monoxide: Organic residues and waste materials can be gasified to synthesis gas, which contains carbon monoxide as a carbon source. Both chemical-catalytic (Fischer-Tropsch) and biotechnological processes can use carbon monoxide as a raw material for the production of chemical products. One example is the biotechnological production of ethanol or ethylene from metallurgical gases (Lanzatech, 2020).

The raw materials and product examples mentioned show that the recycling of carbon in various forms is already practice and has further industrial potential. It should be taken into account that the raw material spectrum will change as the raw material shift from fossil to renewable carbon sources continues. The share of biomass and biogenic residues and waste will increase and that of fossil raw materials will decrease. As individual industries begin to switch to hydrogen and electricity, as can be seen in steel production (ArcelorMittal, 2020), the supply of metallurgical gases as a carbon source will also tend to decrease.

This is a process of change that will take decades. Nevertheless, industry and policymakers must prepare for this today because the development of the relevant processes, the adaptation of industrial plants and the infrastructure also takes time, investments, and requires the coordination of numerous players.

For the use of biomass, agriculture and forestry must be integrated into industrial value chains. The same applies to the use of agricultural residues, for which, because they do not compete with food, social acceptance can be more readily expected. In the recycling of plastics, waste management will become more important for closing this material cycle, and because this sector is often closely linked to public administration, so will it. The same applies to the gasification of waste into synthesis gas; here, too, the infrastructure of waste management is a fundamental prerequisite. The use of syngas and CO_2 from industrial emission streams will require integration with the energy sector because of the high demand for reduction equivalents or energies.

The transition to the new economic structure thus created is in itself a major challenge. In addition, demand expectations are placed on individual sectors that will foreseeably reach their limits, particularly with regard to the provision of carbon sources and energies. Biomass and the residual and waste

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materials derived from it, which ultimately come from agriculture and forestry, are considered an important source of sustainable carbon. Their land areas cannot be expanded at will and are already so ecologically burdened today that conservation rather than even more intensive use would be recommended. The chemical industry should therefore not depend exclusively on biogenic carbon sources. Relief is offered by the use of CO_2 and CO, which, however, also has its limits due to the high energy requirements for the production of the necessary reduction equivalents. Because plastics account for a large share of chemical production and thus also of Scope 3 emissions, there are justified calls to intensify plastics recycling. In fact, a roadmap for sustainable chemistry in Germany proposes to develop and implement all the options mentioned. According to this study, in order to achieve climate neutrality, CO_2 will become the most important carbon source in the chemical industry in Germany by 2050, alongside biomass and plastics recycling. Admittedly, this goes hand in hand with an additional electricity demand almost equal to Germany's full consumption today (Dechema and Futurecamp, 2019).

4 What needs to be done to support this path towards a truly climate-neutral chemical industry that also reduces Scope 3-related emissions?

In my view, two measures are urgent here:
Firstly, Scope 3 emissions must be included in the ETS and burden either the producing or the disposing industry. Only then will the framework provide an incentive to reduce CO_2 emissions from product-bound carbon and switch to renewable carbon sources. However, this tightening of the ETS will only have the desired effect if at the same time emission streams that are recycled are released from the ETS. Today, emissions subject to the ETS incur costs regardless of whether they are recycled or released into the atmosphere.

Secondly, the technical recycling of CO_2 can only be scaled up if the necessary energies are available in sufficient quantities and without emissions. In Europe's most important chemical regions, such as North Rhine-Westphalia in Germany, Flanders in Belgium or the southern Netherlands, large capacities of bioenergy, solar and wind power are being built up. It is doubtful whether these regional and nationwide capacities are sufficient to cover the growing demand for electricity, not only for industry but also for mobility and heating. The European framework conditions should therefore encourage to build an Europe-wide infrastructure for renewable energies, linking the large energy consumers in the north - the example of the ARRR chemical region (Antwerp, Rotterdam, Rhine-Ruhr) has been mentioned only as an example - with locations for solar and wind energy in the sunny south of Europe that are to be developed. The electricity could also be distributed via the existing natural gas grid in the form of hydrogen, which is actually needed by the chemical industry for CO_2 recycling. Further potential is offered by geothermal energy in Iceland, which is far from being fully exploited, and hydroelectric power in Scandinavia. Some countries, such as France and the Netherlands, are also keeping respectively reviving nuclear energy. Such regions could replace the currently dominant non-European suppliers of fossil energy sources and thus share in the value creation of the chemical sector. In fact, the implementation of this strategy has already begun; however, not in the EU, but further south, where large hydrogen capacities based on solar and wind energy are being built in Saudi Arabia (NEOM, 2020) and Morocco (DII, 2020) for export.

In summary, I believe that renewable carbon sources from biomass, plastics and CO_2 recycling are technically feasible today and should be implemented vigorously. Inhibiting factors are i) insufficient and too expensive capacities for emission-free energies and ii) in Europe, the framework conditions, especially the ETS. The fact that distortions of competition with non-European markets must be avoided in the further development of the framework conditions adds further complexity. Nevertheless, in the interest of urgent climate protection, long-term prosperity and competitiveness based on sustainability, business and politics must face up to the task of removing the technical, economic and political obstacles and unleashing driving forces sooner rather than later. Time and climate change are pressing.

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Research Paper

Graham Gibson*

The Strategic Approach to International Chemicals Management: A case study of transnational public-private partnerships in the chemicals sector

As an international effort to improve practices worldwide, the Strategic Approach to International Chemicals Management (SAICM) is an overarching policy framework intended to complement existing agreements within the global chemicals sector by serving as a platform for the engagement of a wide variety of stakeholders. This work identifies SAICM as a transnational public-private partnership (TPPP), conceptualizing it as part of a wider movement within international environmental governance. The paper proceeds to analyze SAICM utilizing a theory-testing process tracing method to test whether the prevailing theories on the effectiveness of such partnerships are supported in the case of SAICM. In doing so, the researcher offers valuable insight into the strengths and limitations of the TPPP approach in the chemicals sector, which can be of use for stakeholders involved in the negotiations to be held for an agreement on a new SAICM.

1 Introduction

Clearly, the issue of sustainability in the chemicals sector is a pressing one for the economy, human health, and the environment; this reality has been acknowledged by the international community through a host of initiatives, including the creation of the Strategic Approach to International Chemicals Management (SAICM) in 2006. This paper explores the strengths and weaknesses of the transnational public-private partnership (TPPP) approach utilized in SAICM. Through the utilization of a theory-testing process tracing method, the work contributes not only to this field's established research gap in case studies, but also illuminates theoretical considerations for policy-makers and other stakeholders to consider during future negotiations for a new SAICM.

2 Background

The multi-stakeholder, cooperative approach to transnational environmental problems can be seen as a distinct movement within international environmental governance. According to Jänicke and Jörgens (2006, p. 172): "the first phase of environmental policy in the late 1960's and 1970's was dominated by the traditional dipole of the state as the originator of policy and industry on the receiving end". Intergovernmental regimes remained the focus throughout the 1980's, while transnational actors and networks were largely dismissed as "epiphenomenal" (Bulkeley et al., 2009, p. 54). However, the global governance sphere began to move in a different direction in the following decade and beyond.

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The 1992 Earth Summit constituted a pivotal moment for international environmental governance. This meeting produced Agenda 21, a comprehensive plan of action for all policy levels that was agreed upon by 178 national governments (United Nations [UN], n.d.). Jänicke and Jörgens (2006, p. 176) refer to Agenda 21 as the "most ambitious approach to environmental governance", with key elements being identified as:

1. **Strategic approach** – consensual, generalized targets and long-term strategy formulation
2. **Integration** – incorporation of environmental issues in other policy areas
3. **Participation** – significant participation of NGOs and citizens
4. **Cooperation** – between private and public actors in decision-making and enforcement
5. **Monitoring** – monitoring success with a variety of reporting obligations and indicators

Agenda 21 disperses responsibilities to different sectors beyond government and "aims overall to replace reactive, additive, case-by-case policy decision-making to protect the environment with broad-based global, national, and local efforts" (Jänicke and Jörgens, 2006, p. 177). According to Dodds (2015), this kind of decentralized and participatory approach came to be known as Type II partnerships.

These types of partnerships have become "a cornerstone of the current global environmental order, both in discursive and material terms" (Pattberg, 2010, p. 280). As a result of this development, "environmental governance is therefore caught up in a complex web of state and non-state actors operating and interacting at different policy levels" (Jänicke and Jörgens, 2006, p. 173). This sort of convoluted and mixed governance structure, in which a variety of actors are interacting with each other at different levels in the same sector, is where SAICM operates. Jänick depicts this phenomenon in Figure 1 as the dimensions of modern environmental governance.

The underlying idea is that different partners at different levels in different sectors bring their unique resources and strengths to the targeted issue, while the weaknesses or gaps of individual stakeholders are supplemented or complemented by the other partners. Detomasi (2007) gives us a graphic representation (Figure 2) of what strengths and weaknesses each different type of stakeholder typically brings to problem solving in transnational issues. This further reflects the underlying logic of Type II partnerships that would come to be so influential on SAICM.

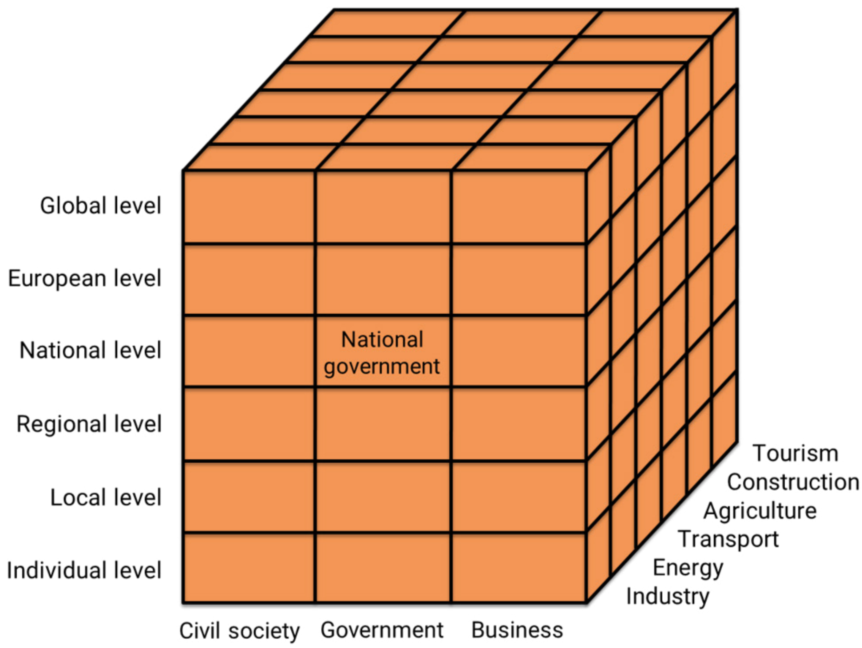

Figure 1 Dimensions of Modern Environmental Governance (source: Jänicke 2006).

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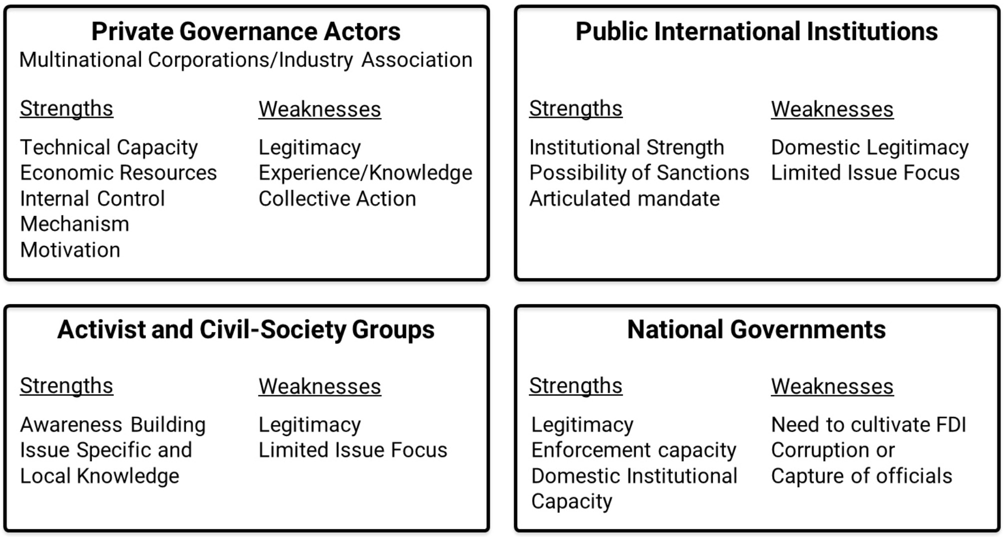

Figure 2 Global governance and corporate social responsibility participating actors (source: Detomasi 2007).

On the official SAICM website, its approach is described as such (SAICM, n.d.):

SAICM provides a valuable multi-stakeholder forum to discuss and address the many challenges facing the adoption and implementation of national policies to safely manage chemicals. SAICM is an ambitious initiative and is unique in its set-up as an inclusive, voluntary, global policy framework on the sound management of chemicals across the lifecycle.

Three core documents initially comprised SAICM: the Dubai Declaration on International Chemicals Management, the Overarching Policy Strategy, and the Global Plan of Action. First, the Dubai Declaration serves essentially as recognition of the existing efforts that have taken place in chemicals and waste management and an affirmation of SAICM's commitment to the sort of partnerships outlined in Agenda 21 (United Nations Environment Programme [UNEP], n.d). Second, the Overarching Policy Strategy (OPS) explicitly identifies the five main policy objectives of SAICM, which are as follows (UNEP, n.d.):

1. Risk reduction
2. Knowledge and information
3. Governance
4. Capacity building and technical cooperation
5. Illegal international traffic

Additionally, some notable financial features call for (UNEP, n.d.):

- Actions by national or sub-level governments for financing of objectives
- Enhancing industry partnerships and financial and participation in implementation
- Integration of objectives into multilateral and bilateral development assistance cooperation
- The establishment of a Quick Start Programme (QSP) to facilitate implementation and achievement of objectives
- Appointing of National Focus Points (NFPs)
- Periodic reviews during International Conferences on Chemical Management (ICCMs) held every four years and conducting of regional and other meetings between these ICCM gatherings
- Establishment of a SAICM Secretariat that is responsible for facilitating meetings, disseminating information/ guidance, maintaining partnerships, and more

Finally, the Global Plan of Action (GPA) "lists possible work areas and 299 associated activities, as well as actors, targets/ time-frames, indicators of progress, and implementation aspects" (UNEP, 2019, p. 225). These include: occupational and children's health and safety, cleaner production, waste management and minimization, hazard data generation and availability, and more (UNEP, n.d.). Furthermore, it is also noted that the GPA should be considered an "evolving tool" (UNEP, n.d., p. 27).

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The next meeting of the ICCM, ICCM 5, was set to take place in Bonn, Germany, in October 2020, but has been postponed due to the global pandemic caused by COVID-19 (International Institute for Sustainable Development [IISD], 2020). A new framework will need to be negotiated eventually, as the mandate of the current SAICM framework expired in 2020. This new framework is often referred to as the SAICM Beyond 2020 Framework. A wide range of stakeholders are expected to take part in the discussions, as many expressed satisfaction with SAICM's inclusive approach, regarding it as an ideal platform for advancing sustainability in the chemicals sector (IISD Reporting Services, 2015). This paper can contribute to discussions at ICCM 5 through a critical evaluation of the strengths and weaknesses of SAICM through the framework of TPPPs. These findings can help better inform decision-makers and stakeholders during the negotiation process for a SAICM Beyond 2020 framework.

3 Literature Review

Börzel and Risse (2005, p. 4) define TPPPs as a unique form of governance, specifically: "institutionalized cooperative relationships between public actors (both government and international government organizations) and private actors beyond the nation-state for governance purposes". Although the academic debate over definitions of TPPPs is lively, overall, Schäferhoff, Kampe, and Caan (2009, p. 453) offer a succinct summary of this litany of definitions, stating: "the bottom line of all definitions is that transnational public-private partnerships are continuing and relatively institutionalized transboundary interactions, which include public actors, such as government and international organizations, and private actors".

It is nevertheless important to describe some of the key characteristics of TPPPs. First, Jänicke and Jörgens (2006) argue that such partnerships are more easily reached in industries with only a few main actors, which characterizes global basic chemical and pharmaceutical production (UNEP, 2019). Additionally, Pattberg, Biermann, Chan, and Mert (2012) identified important shared characteristics found in the literature of TPPPs: cross-border and non-state relations, public policy objectives, and a network structure, appearing in different sectors and entailing different scopes of geography. More recently, Sun (2015) has identified two main features of TPPPs – first, as they are created through a system of voluntary cooperation, their governance authority is obtained through both public and private spheres, as opposed to deriving from delegation, market mechanisms, or moral authority; second, they are a form of governance based on networks of public and private actors, which interact in decentralized or adaptable ways.

The theorized advantages and disadvantages offered by TPPPs are also present in existing literature. Hale and Mauzerall (2004) express the perceived strengths of this approach as being trifold: pooling together of partners into an optimal coalition, focusing resources and activities from a broad commitment towards specific projects, and improved coherence of sustainable development efforts. Furthermore, Biermann, Chan, Mert, and Pattberg (2012) identify the creation, implementation, and inclusivity of norms as popular arguments made for TPPPs. On the other hand, the multi-stakeholder approach embraced by TPPPs is also be handicapped by a series of limitations. Börzel and Risse (2005, p. 15) argue that these TPPPs are liable to lead to "lowest common denominator" solutions, i.e. business interests, as those who would likely have to bear the economic cost of changes in standards of the chemicals industry, have a role in the international rules setting and do their best to make any results as minor or negligible as possible. This can also exclude other civil society stakeholders by nullifying the importance of their input during negotiations. This sentiment is echoed by Hale and Mauzerall (2004), who express concern that these TPPPs can serve as a vehicle for 'blue-washing', or the hiding of environmentally problematic behavior behind a sort of façade, usurping international reputation and validity. On the other hand, Chan and Müller (2012), taking an institutional perspective, argue that this sort of capitulation can originate from the side of the public sector, as policy makers with limited time and/or resources may revert to sub-optimal solutions rather than pursue more effective, but possibly more difficult, changes.

4. Research questions and methodology

The researcher further draws from the comprehensive review of TPPP literature developed by Pattberg and Widerberg (2015). Based on existing academic literature, the authors identify nine conditions, which are subsequently grouped into three themes:

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Actors

1. Optimal partner mix
2. Effective leadership

Processes

3. Stringent goal-setting
4. Sustained funding
5. Professional process management
6. Regular monitoring, reporting, and evaluation to support organizational learning

Context

7. Active meta-governance
8. Favorable political and social context
9. Fit to problem structure

The research questions pursued draws on these conditions, as well as the contextual and theoretical elements discussed above, and are articulated as follows:

1. *What have been the strengths and weaknesses in the approach utilized in the Strategic Approach to International Chemicals Management (SAICM)?*

2. *Do these findings support the existing theory on conditional factors articulated by Pattberg and Widerberg (2015)?*

The first question is an exploratory one; it will be answered in a factual manner from the data sources. The second question is a theory-testing question, which requires theory-testing process tracing method as described by Beach and Pederson (2013). SAICM is unique within the chemicals sector because it differs from other existing agreements in chemicals management for its non-binding nature, its broad scope of activities, and the fact that non-government actors are allowed to participate in the main decision-making body, the ICCM (Persson et al., 2014). These characteristics, as well as its ongoing renewal process, establish SAICM as an ideal case study for the use of method.

The researcher largely employed a literature review to collect the relevant data. Data is derived from a variety of sources, including SAICM resolutions, texts, reports, and other official documents produced from and related to the ICCMs and other SAICM meetings. In their method, Beach and Pederson (2013) refer to triangulation, or the collecting of multiple independent evaluations, as a way to increase the veracity of the hypothesis, which the researcher has also done with these different sources. The high quality and diversity of this data qualifies it as evidence, which is important because it will allow the researcher to draw observations on whether the case of SAICM supports confirmation or disconfirmation of the nine conditions. Additionally, public policy literature presents three critical ways to understand results: outputs, outcomes, and impacts, which are defined as (Köppel and Sprinz, 2019, p. 1862):

- **Outputs** – "the norms, principles, and rules that states adopt when implementing a regime"
- **Outcomes** – "regime-induced changes in human behavior"
- **Impacts** – "changes in environmental quality – the biophysical environment itself"

These concepts will be important to understanding and interpreting the results.

The development of an analytical model based on the method of Beach and Pederson (2013) will allow for the interpretation of evidence and the addressing of the second research question. First, the independent variable (X) and the dependent variable (Y) of the experiment need to conceptualized. The independent variable is SAICM itself; conversely, the dependent variable is identified as the results of SAICM. Seeing as a causal mechanism is often composed of various components, and explains the causal relationship between X and Y (Beach and Pederson, 2013), the causal mechanism in this case is conceptualized as the nine conditions (and their respective three overarching groups)

Figure 3 Analytical model (own representation).

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identified by Pattberg and Widerberg (2015). Therefore, the developed analytical model for this thesis is demonstrated in Figure 3. This doubles-sided interpretation – that is, of the conditions influencing the effectiveness of the SAICM throughout its the policy life cycle, as well as of its results– will allow the researcher to thoroughly address the second research question, and thus elucidate some policy insight for SAICM Beyond 2020.

5 Results

First, an independent evaluation was sanctioned by SAICM to carry out an analysis of its activities from 2006-2015. It was written by Dr. Robert Nurick and cites numerous strengths in SAICM. First, SAICM delivered on some of its outputs through the successful arranging of meetings and conferences, crafting of resolutions, and establishment of the Secretariat (Nurick, 2019). From this, SAICM has also demonstrated some degree of success it delivering its outcomes, particularly regarding the QSP , specifically: successful mainstream of chemicals management on the national policy level, high impact of implemented projects (particularly when involving partnerships between governments and NGOs), the ability to secure external funding to continue their work after conclusion of SAICM funding, and significant improvement in political and technical awareness of the importance of sound chemicals management (Nurick, 2019). Overall, 184 projects were approved and 70 had been completed by 2015, addressing all objectives of the OPS (Nurick, 2019). Additionally, another outcome with which SAICM successfully engaged was the identification of emerging policy issues (EPIs). SAICM succeeded in raising the profile of these issues on the international policy level, especially regarding lead in paint and the subsequent formation of the Global Alliance to End Paint in Lead (Nurick, 2019). Finally, there was some success in strengthening the capacity, commitment, and political will to mainstream SAICM. For example, 18 countries in Africa developed NFPs for this purpose, followed by 13 in the Latin American and the Caribbean Region, 8 in the Asia-Pacific Region, 8 in the Western Europe and Others Group, and 6 in the Central-Eastern European Region; progress was also made in attempts to organize cooperation within geographic regions (Nurick, 2019).

On the other hand, the report also finds some weaknesses demonstrated by SAICM. First, Nurick (2019) argues that the drivers of change, particularly adequate financing, were severely restrained. An example of this ever-present issue of funding is the SAICM Secretariat, for which funding fell short by at least 43% for six of the 10 years included in this study and which was underfunded for all but 10 months of this entire period (Nurick, 2019). This hampered the ability of the Secretariat to disseminate knowledge and information, further diminishing the outcomes and impacts achieved (Nurick, 2019). Second, it criticizes the indicators chosen for the GPA, as they were based solely on outputs, without complementary outcomes- and impacts-based indicators; this made the processes for monitoring and reviewing progress much more difficult (Nurick, 2019). Third, the presence and participation of several important stakeholder groups was missing or lacking. Academia was largely missing due to a lack of an integrated scientific body and the declining of an offer made by various chemical societies to become official advisory scientific bodies; simultaneously, participation from industry was limited to chemical producers and failed to include downstream users, retailers, and others (Nurick, 2019). Finally, information and knowledge sharing between stakeholders remains a persistent issue for a number of reasons, including reluctance to do so by business actors, limitations of the Secretariat, and weak communication between different levels of governments within some nations (Nurick, 2019).

Second, a report commissioned by the Finish Ministry of the Environment and carried out by the Center for Governance and Sustainability also found many shortcomings. Urho (2018, p. 6) largely contributes these to governance structure, stating: “this is explained by the fact that SAICM was designed to work differently than conventional approaches by mobilizing support from other actors, rather than actively participating in their delivery through internal structures”. Specifically, Urho (2018, p. 36) criticizes this formulation of SAICM’s goal, stating: “the overall objective may fall short, since it is heavily qualified”. Second, Urho criticizes the effectiveness of National Action Plans (NAPs), stating: “the lack of a strategically prioritized NAP mechanism has resulted in an ad hoc and sporadic approach to development of NAPs with different names and approaches, making it challenging to assess collective progress” (Urho, 2018, p. 45). Third, Urho (2018) points out that reporting for the indicators of the 273 GPA activities are often not reported or followed-up on, and that the indicators are under-developed and overly broad to ensure effective reporting. Fourth, regarding reviewing and monitoring, Urho (2018) criticizes the lack of a review mechanism for individual reports, arguing that it could help

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countries with useful advice for progress. Fifth and finally, Urho (2018) offers a positive assessment of the process for identifying of EPIs and the productions of the Global Chemical Outlook series of reports, but criticizes SAICM's lack of any permanent internal mechanism to serve as a science-policy nexus, particularly an over-reliance on IOMC institutions that suffer a lack of resources and funding to handle this extra responsibility heaped upon them.

Finally, in a 2018 conference paper, Simon and Schulte note some weaknesses in SAICM's approach. They discuss SAICM's measurable goals and objectives, pointing out that: "the OPS neither sets priorities among these objectives, nor does it call on stakeholders to reach certain goals or targets by a defined deadline" (Simon and Schulte, 2018, p. 2). Despite attempts towards effective assessment at ICCM 2, Simon and Schulte (2018) argue that numerous shortcomings remained in the utilized measurement tools, specifically that the indicators adopted missed key regulatory developments, such as the development of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation in Europe. To further this point, Simon and Schulte criticize the loose terminology, where terms such as 'vision', 'targets', 'objectives', 'indicators', and more are seemingly used in an interchangeable manner. Simon and Schulte (2018) also noted the low level of reporting by stakeholders, even when compared to MEAs generally. Finally, Simon and Schulte (2018) offer some criticism on the meaningfulness of discussion, pointing out that, despite delegates expressing an interesting in developing a proposal on the inclusion into SAICM of the 2030 Agenda for Sustainable Development, a working group was never created due to a lack of funding. Overall, these sources paint a relatively dim picture of SAICM's successes, which were notable but limited, while also identifying key shortcomings. This is reflected by the general consensus amongst SAICM stakeholders by the end of ICCM 4 that that the goals of SAICM would not be reached and that, accordingly, most of the focus by had been adjusted to laying the groundwork for a successful ICCM 5 and to a SAICM Beyond 2020 agreement (IISD Reporting Services, 2015).

6 Interpretation

According to the methodology already described, the causal mechanism identified is the nine conditions for the effectiveness of TPPPs articulated by Pattberg and Widerberg (2015). The remaining steps will be to assess each individual aspect of the causal mechanism and use the theory-testing process tracing method to weigh evidence and make causal inferences in testing the second research question. This will enable the testing of the hypotheses and elucidate policy insights for SAICM stakeholders.

Actors

1. Optimal partner mix

   The omission of prominent stakeholder groups can lead to lower performance (Pattberg and Widerberg, 2015). Nurick (2019) identifies the lack of involvement and participation from academic actors as a significant weakness, as well as the lack of integration of a wider range of downstream business and industry actors beyond chemical producers. Furthermore, there was no concerted effort to involve women or other marginalized groups in QSP activities (Nurick and Touni, 2015). Finally, SAICM resolutions itself calls for greater involvement of the health sector (UNEP, n.d.). This evidence supports the validity of the nine conditions, as it has served as an expected limitation.

2. Effective leadership

   Effective leadership is necessary for "bringing people to the table, mitigating diverging opinions, and driving the difficult start-up process" (Pattberg and Widerberg, 2015, p. 47). In this regard, the establishment of the Bureau and a Secretariat at ICCM2 represent successful outputs, as do the ability to convene regular meetings, particularly the open-ended working groups (OEWGs) and intersessional meetings. This supports the validity of the nine conditions; the leadership of UNEP and the Inter-Organization Programme for the Sound Management of Chemicals (IOMC) have been key in obtaining the successes SAICM has demonstrated. However, Nurick (2019) argues that the Secretariat was limited in its capacity for various reasons, which will also be touched on in other conditions and limited SAICM's effectiveness by, for example, limiting its ability to communicate best practices.

Processes

3. Stringent goal-setting

   Stringent goal-setting is important, as Pattberg and Widerberg (2015, p. 47) state: "in many cases, rules are so vague and broad that they impede compliance, monitoring, reporting, and evaluation, and consequently

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limit accountability and transparency". Here, the evidence paints a bleak picture of the SAICM results, one that support the validity of the nine conditions. Simon and Schulte (2018) criticize the goal-setting featured in the SAICM's OPS, as it does not prioritize objectives nor does it set specific deadlines for specific goals, as well as the loose terminology used, with 'targets', 'goals', and 'objectives' seemingly interchangeable. Urho (2018) also criticizes what he sees as this weighty qualification of SAICM's goals, arguing it may limit the SAICM's ability to achieve its objectives.

4. Sustained funding

Pattberg and Widerberg (2015) argue that the issue of funding is more prominent for TPPPs than for other forms of implementation program. The evidence indicates this was also the case in SAICM, although there was some degree of success. On the positive side, in the period from its inception to August 2015, national governments and the European Commission provided almost 40 million dollars to the QSP Trust Fund (Nurick and Touni, 2015). Additionally, Nurick (2019) notes that many of the QSP projects and programmes were able to secure long-term funding following the conclusion of the SAICM financing. However, there were numerous shortcomings in this area as well. For example, Nurick and Touni (2015) state that the expansion of funding sources envisioned in the QSP business plan was never quite achieved. Additionally, the almost continuous shortage of funding for the SAICM Secretariat severely limited its ability to perform its designated function (Nurick, 2019).

5. Professional process management

Pattberg and Widerberg (2015) note the importance of having a full-time staff. Although this is the case in SAICM (UNEP, n.d.), this condition shows many weaknesses that support validity of the nine conditions. For example, Urho (2018) criticized SAICM's over-reliance on IOMC structures that did not have the capacity or resources to handle the extra responsibility that was being thrust upon them. Nurick (2019, p. 69) identifies a weakness in that many of the NFPs delegated SAICM responsibilities to officials in junior positions, saying their role as the NFP for SAICM was largely "invisible".

6. Regular monitoring, reporting, and evaluation to support organizational learning

Pattberg and Widerberg (2015) argue this condition is important for three reasons: institutional learning, demand for financial accountability, and transparency for the sake of legitimacy. The systems embedded within the SAICM structures for monitoring and reporting were found to be largely lacking. For example, Nurick (2019) found the indicators developed to be a weakness, as they were solely outputs-based, without any complementary outcomes- or impacts-based indicators. This criticism is echoed by Urho (2018), who found them to be insufficient and too general. Furthermore, Simon and Schulte (2018) also point to low reporting rates as a weakness of SAICM; in the period from 2011-2013, only 43% of national governments providing report on their national indicators. In terms of evaluation, Urho (2018) criticizes the lack of a review mechanism for individual reports, which hindered the development of institutional learning. These weaknesses lend support to the nine conditions theory, as they align with what would be predicted in terms of hampering effectiveness.

Context

7. Active meta-governance

Pattberg and Widerberg (2015, p. 48) argue this condition is evermore important in an increasingly fragmented landscape in international environmental governance, defining meta-governance as the "organization of self-organization or regulation of self-regulation". Some outputs can be interpreted as successful in terms of endorsing of previous MEAs in the global chemicals sector, as articulated in the founding SAICM resolution (UNEP, n.d.). Here, the lack of integration of the 2030 Agenda and Sustainable Development Goals (SDGs) into the SAICM resolution, despite interest shown by stakeholders for doing so (Simon and Schulte, 2018), stands out as a prominent weakness. This weakness aligns with what would be predicted under the conditional factors, providing support for the theory.

8. Favorable political and social context

The observations show that the SAICM made meaningful progress in promoting a more favorable political and social context for sustainability in the global chemicals sector. For example, the identification of EPIs was noted as an achievement that raised the

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profile of these issues of concern chemically (Urho, 2018; Nurick, 2019), reflecting a successful output. Additionally, the QSP demonstrated success in local projects and mainstreaming chemicals management at the national level policy (Nurick, 2019), which would represent a successful outcome, although Urho (2018) criticizes the lack of a clear NAP mechanism. This evidence would lend support to the tested theory as well, as the conditions, when favorable, facilitated effective results.

9. Fit to problem structure

   Malign problems, or problems "characterized by high levels of complexity, competing interests, and unclear solutions" (Pattberg and Widerberg, 2015, p. 49), are more difficult to solve. The evidence in the case of SAICM provides support for this theory; international chemicals management certainly qualifies as such a malign problem, and it is a problem certainly not solved. This theoretical condition offers an explanation for SAICM's shortcomings; Urho (2018, p. 13) criticizes the "minimalist" governance structure of SAICM as being too reliant on stakeholders. This also provides support towards the confirmation of Pattberg and Widerberg's (2015) work.

Overall, with the evidence interpreted, its inferential value allows the researcher to make causal inference, either supporting the confirmation or disconfirmation of the nine conditions of effectiveness for TPPPs identified by Pattberg and Widerberg (2015). Based on this, the researcher can reasonably infer, based on Bayesian logic of probability and the contextual information and evidence, that the results support confirmation of Pattberg and Widerberg's theory on the nine conditions of the effectiveness of TPPPs. This is because none of the evidence appears to contradict the expected results; when the theory predicts that a certain element will lead to either a strength or weakness, the interpretation has found the predicted result. Although many of the results of the SAICM process are mixed in terms of their effectiveness in creating outputs, outcomes, and impacts, the direction of causality corresponds to the theory, even in these unsuccessful cases. Thus, the analysis supports the confirmation of the Pattberg and Widerberg's (2015) theories on the conditions for the effectiveness of TPPPs. The support demonstrated in this case implies utility for policy-makers and stakeholders to consider when making decisisons during the SMAIC Beycond 2020 process.

making decisions during the SAICM Beyond 2020 process.

7 Conclusion

On a practical level, this article shows that the nine conditions can serve as a sort of roadmap for policy-makers to consider when negotiating the new SAICM Beyond 2020 Framework in 2021. For example, it is established in the theory of Pattberg and Widerberg (2015) that precise goal setting encourages sustained funding. Seeing as these were both identified as significant weaknesses of SAICM, this constitutes an important issue for policy makers to consider in crafting a new agreement, i.e. improving the clarity of goals articulated in the new agreement can facilitate more sustained levels of funding. Another example of a policy recommendation that can be solicited from this work is the need to integrate the SDGs in a SAICM Beyond 2020 agreement in order to develop active meta-governance. In the complicated landscape of global chemicals governance, the SDGs can provide a theoretical foundation and central policy plank on which to build an effective regime, as well as cement the framework as an integral part of the international community's wider sustainability agenda. This could also facilitate stakeholder inclusion vis-à-vis an increased focus on the inclusion of women and marginalized groups. Indeed, more wide-ranging involvement of actors in the chemicals sector, including downstream users, academics, and potentially many readers of this journal, is paramount, as the current partner mix is sub-optimal and limiting. This work sets forward a path that is ripe for continued study. Future researchers can add to this work and elaborate on the interconnections between the various conditions, particularly how they can facilitate or hinder one another. In terms of utility for SAICM Beyond 2020, this could prove beneficial in promoting improved decision making in policy implementation and design. Ultimately, these conditions can serve as points of reference for policy makers to guide the way forward in the SAICM Beyond 2020 process.

With such an increased understanding and a supported theory for the conditions of success for TPPPs, hopefully stakeholders can reach a successful and effective deal. The international community's sustainability goals partly rest upon the shoulders of these actors. For these goals, and the sake of the health of the planet and its people, the sound management of chemicals and waste is imperative.

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Research Paper

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When data science meets patent information – Analyzing complex business environments of innovation-driven industries

The rapid development of the internet as well as the emergence of new technologies such as smart devices leads to an exponential growth of data that hold useful information for companies. To face this trend new methods were developed, which allow to analyze large amounts of data in short time. This enables to investigate topics in a broader context, what again offers interesting new insights. Among the different data types that can be analyzed, especially patents represent an important information source for companies that hold unique technological information. Therefore, analyzing patents can reveal research, technology, and innovation activities in industries, which enhance a company's decision making in relation to its R&D activities by better understanding its complex environment. This makes the patent analysis an indispensable task for companies. In this article, we aim to show case the ease and value of data-driven patent analysis. Already simple methods such as counting or connecting single patent information reveal through different visualization various insights in a business environment and improve its understanding. Towards this goal, we provide four case studies based on patents stemming from the fields of stem cells, lithium-based batteries, antibiotics, and personalized medicine. Thereby, each case features different data mining techniques to present readers a broad range of application examples.

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1 Introduction

The rapid networking of the modern world caused a widely spread of knowledge and technologies, which consequently led to an increasing rate of change due to shorter product life cycles (Qualls et al., 1981), increasing technological changes (Sood and Tellis, 2005), increasing innovation speed (Parry et al., 2009) and an increasing speed of the diffusion of innovations (Lee et al., 2003). Due to these developments, the world is characterized by growing environmental changes and complexity, which must be considered in a company's strategy. On the one hand, results a growing necessity to create innovations to survive in an environment that is characterized by pervasive, unpredictable, and continuous changes (Aydogan, 2009). On the other hand, the growing complexity hampers the innovation capabilities of companies because it requires the observation of the whole environment for changes to overcome the uncertainty of the company and be able to respond to changes in time (Day and Schoemaker, 2004). However, the understanding of the environment requires the gathering and analysis of external data sources. Through the rapid development of the internet in combination with the emergence of new devices, such as smart phones, the amount of data grows exponentially. Estimations in 2015 presented that roughly 90% of the data all over the world was created in the two preceding years due to the emergence of new devices, sensors, and technologies (Kroker, 2015). While the opportunities to analyze and use external data for the own strategic purpose grow, the investigation of the growing amount of information becomes an increasingly harder task that results in an enormous expenditure on desk research and exceeds the capacities of companies. Hence, to face the so called data explosion and fully exploit its potential new analysis methods were needed. For this purpose, the field of data science emerged that aims to extract knowledge from great amounts of data.

Data science is a field that developed due to advances in hardware and software technology over the years. It focuses on processing high quantities of data through the development of algorithms or respectively statistical methods to find hidden patterns in large datasets. Data science methods extends the manual analysis by enabling not only to analyze single parameters but to analyze combinations of parameters, whereby hidden connections with higher strategic significance, in comparison to isolated key figures, can be revealed (Ernst, 2003; Siwczyk, 2010). Therefore, data science methods changed the way we can analyze data, what enables companies to get a broader and deeper look on data. In return companies can exploit data sources to better understand their environment, which enhance their decision making. It results that these methods became indispensable for companies to gain unique knowledge from data that could lead to competitive advantages. Noteworthy is that the developments of the internet and new devices not only caused growing amounts of data but also promotes a greater variety. Depending on what type of data is analyzed different information about the environment can be investigated. For instance, scientific publications mostly hold information about basic and applied research while social networks may rather represent social opinions (Kayser, 2016). Among the variety of data types, especially patents represent a source with unique information, whose analysis with data science methods can create great benefits for companies.

Patents are a primary data source for technological information that are well suited to be analyzed by data science methods. What distinguishes patents from other information sources is that 80 per cent of their content is not available anywhere else (Dou, 2005). Furthermore, a higher level of detail and range of information results in a more comprehensive information source in comparison to other sources such as scientific publications (Bonino et al., 2010). Generally, patents are used for legal protection of innovations, which has especially in innovation-driven industries great importance (Reitzig 2004; Smith and Hansen, 2002). They can strengthen a company's competitive standing by systematically limiting the scope of action of competitors (Hentschel, 2007). Moreover, they can open up access to complementary patents of competitors through the usage of patents as a kind of currency in cross-licensing agreements (Hentschel, 2007). It also play an important role in the case of decision making relating to cooperation partners as well as merger and acquisition, because a well-positioned and balanced patent portfolio represents an important strategic factor. Consequently, analyzing patent data enables to grasp research, technology, and innovation activities in industries, wherefore patents can be used as an indicator for the creation of knowledge as well as for empiric innovation research. Therefore, combining patents and data science methods can offer huge potential for understanding business environments and trends, which enhances decision making.

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With this paper we want to provide readers with an initial understanding of the application of data science methodologies on patents. Therefore, we present 4 case studies taken from highly relevant technological fields. These cases are only analyzed with simple data science methods that deal with counting certain information like application numbers or linking information like frequencies of patent applications with patent applicants. By considering different information in the patent data and using methods to visualize the results in different ways, the variety of insights in the industries that can be grasped by these methods will be presented. Concluding, the execution of these cases is also intended to give the readers insights how patent analysis through simple data science methods can be a contribution to understand business environments. The remainder is of this paper is organized as follows: Section 2 briefly describes the theoretical background for the research setting. Section 3 presents the four case studies including the analyses steps and their results. At last, section 4 summarizes the major findings followed by a conclusion and limitations in section 5.

2 Theoretical Background

2.1 Data Science

The growing amount of available data attract the attention of many industries, which realized great potential to achieve competitive advantages through its analysis. Although, companies possess teams of statisticians and modelers that can exploit datasets, the vast amount of data exceeds the possibility for manual analyses by far. Meanwhile, strong improvements in hardware lead to far more powerful computers, which allow to develop algorithms that analyze connections between multiple datasets to get a deeper and broader insight into data. The convergence of both developments resulted in the emergence of the data science field. Data science includes principles, processes, and techniques to (automatically) extract knowledge from data. Therefore, an understanding for new phenomena or respectively the company's environment based on data can be built that enhances decision making. Here, the resulting data-driven-decision-making does not completely replace previous procedures for decision making but supports decisions that based purely on intuition before. The effect of this procedure on firm performance was measured by Brynjolfsson, Hitt & Kim (2011), who showed a positive correlation between the application of data based decision making and the profitability of a company. For this reason, more and more companies from different industries started to apply data science methods to improve their business. Depending on the industry, different techniques and types of data are needed. So, delivery services like UPS uses data science algorithms to analyze traffic data from their employees in combination with further data information such as weather or logistics data to optimize its package transport from drop-off to delivery (Samuels, 2017). The health care sector uses data science methods among other things in cancer care. To offer patients personalized chemotherapy and radiation regimens data of cancer patients from the past years in form of diagnoses, treatment plans, outcomes and side effects is analyzed to derive personalized recommendations for future cancer patients (Rice, 2019). Quite different, companies who focus on the online market such as Google or respectively E-Commerce like diverse retailers analyze the data profiles of the internet users (Rice, 2019). Therefore, behavioral patterns can be derived, which enable to create customized layouts and spotlighted products. Also, the price of products can be personalized depending on the users profile, from which his willingness to pay can be derived. In conclusion, depending on the industry different sorts of data and therefore different insights can be important for the business. When we take a look at innovation-driven industries, such as the pharmaceutical industry, especially patent data play an important role (Reitzig 2004; Smith and Hansen, 2002), because creating and patenting innovations involve high costs and efforts. While in many other industries data can be used to optimize the business, innovation-driven industries are strongly dependent on patents due to their strong influence on the performance of the business. Therefore, patents for such industries contain extensive and vital information about their environment. For this reason, patent data and its relevance are the focus of this paper.

2.2 Patents and their relevance

Patent law is a worldwide accepted and established process to protect innovative products or processes, which has gained great importance especially in innovation-driven industries This is represented through the numbers of patent applications, which has been rising since 1990. In 2018 already the German patent office Deutsches Patent- und Markenamt (DPMA) received over 67.000 patent applications (DPMA, 2018) and the worldwide patent

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application grew by five per cent in the same year compared to the previous year (WIPO, 2019). Patents represent a unique form of publications because their acceptance depends on general legal conditions. These take into consideration that inventions to be patented have to fulfill the following requirements being a novel invention, inventive activity must be present and industrial applicability must be possible. Also, the invention with a detailed description must be made public, what does not guarantee that the invention will be patented and could be a risk for the inventor. Only when all these conditions are fulfilled, the patent with its legal protection can be granted. Therefore, patents differentiate themselves from other publications such as scientific journals or books, because the grant of a patent is associated with greater hurdles. For this reason, patents are a more reliable source in comparison to other sources.

Patents represent further an information source with various advantageous properties for analyses, which Dreßler (2006) had summarized. Firstly, the patent applicant is obligated to reveal all technical details of the invention that is to protect. Therefore, patent information is **freely available** in the public database of the responsible patent office for every user group. Additionally, through the progress of the digitalization of information, a quick access and research via internet is favored. Moreover, the information is revealed before the market launch, which enables among other things an analysis of the technological state of the art. From this can be concluded that patents are suitable for representing the most recent trajectory of technologies to predict future trends, which makes them indicators for early trend detection due to its **high actuality**. The neutral audit process through public authorities leads further to an **objective assessment** and due to the implementation of a uniform classification system patents are standardized. Another requirement on patents is that they have to be **understandable** described to make the invention and its value comprehensible for everyone. The introduction of a patent classification system, such as the international patent classification called IPC, enables to **precisely** describe a technology and to classify patents into technology classes. This makes patents more comparable and enhances the search for certain technology fields. At last, with the application of a patent the **commercial value** must be given. This means, that accepted patents represent technologies with potential for commercial usage. Consequently, analyzing patent data with data science methods in terms of patent management can offer important technical, business, and legal insights (Park et al., 2013), which in sum supports companies to understand the big picture.

2.3 Patent structure and information

The structure of patents consists of bibliographic and technical data of an invention. The structure can also be divided into a structured and unstructured part. Data in general can possess a structured, semi-structured or unstructured form (Tanwar et al., 2015). This leads to a structural heterogeneity, while only a small part of all data is structured (Cukier, 2010). Structured data is represented through tabular data and is managed with relational databases and spreadsheets. Each data point possesses a clear relation to the others, which enables to store them with traditional row-column databases such as SQL. Structured data is further characterized by being highly organized and easily machine-processable. The management of the data with relational databases enables a user to quickly input, search, and manipulate structured data (Din, 1994). The Table 1 shows an example for structured data, where each information of a customer can be easily stored in the relational database because of the relation of each information to a column. Moreover, the data can be directly analyzed, for example on which date the most customers were recorded, without the need for any further steps.

In contrast, data without format, schema, or structure is referred to as unstructured data. It can possess any form such as texts, videos, images, or PDFs. While structured data

Table 1 Example for structured data based on customer data (own representation).

ID	User	Address	Phone	Date
1	Karl	123 Apple St.	17 27812	24-03-2020
2	Janice	321 Melon Ave.	17 98832	24-03-2020
...	...	...	...	...

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can be easily processed by machines, the processing and analysis of unstructured data by machines is complicated (Allahyari et al. 2017). An example for unstructured data is the following sentence.

"The customer Carl has made a transaction on the 24th of March 2020."

The form of this data type hinders the storage of the data into a relational database. As a result, the implementation of analysis steps requires preprocessing steps to enable the storage of information from the text into a relational database. In other words, the unstructured text has to be first converted into a structured format to obtain a machine-readable form and be able to gain insights from the data.

Patents possess a semi-structured format. Table 2 shows that most of patent information is structured, such as the IPC codes, and can be directly used for analyses. The structured part of patents includes bibliographic data, which represents information about formalities such as the inventor, application date or technology classification through IPC. The unstructured part is represented through descriptive texts such as the abstract or claims. Although, the text data in patents can be assigned to title, abstract, claims and description, the information is unstructured in themselves. Therefore, specific data science methods must be applied first to analyze these parts of patents.

The broad range of information allows to analyze many different aspects of an invention. For example, from the assignment of patents to its applicant, important strategic information about the competitive environment can be derived. This includes the identification of growing

Table 2 Information of patent documents (source: Song, 2015).

Data type	Information	Description
Structured data	Priority date	Date of worldwide first application.
	Application date	Date of the application at the patent office.
	Publication date	Publication 18 months after application.
	Grant date	Date when the patent is granted.
	Patent office	Name of the patent office.
	Inventor	Inventor of the invention.
	Applicant	Owner of the right.
	Patent classification code (IPC)	Assignment of the invention to a technology class.
	Forward citation	Other patents which cited the considered patent.
	Backward citation	Other patents that are cited in the considered patent.
Unstructured data	Title	Title of the patent.
	Abstract	Brief description of the patent.
	Claims	Definition of the extent of the protection.
	Description	Detailed description of the invention.

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danger potential from competitive companies but also the estimation of the freedom to operate in the own R&D efforts to act with foresight and prevent unnecessary spending of resources. Moreover, different aspects can put into context to find correlations or hidden patterns in the patent landscape. For instance, the analysis of the number of applications in a certain technology area over the years can reveal how the research effort in general has developed, which enable to draw conclusions about the future potential of this research field. However, when the number of application is analyzed in relation to the applicants it may reveal a ranking with the most active players in that field. Therefore, further implications can be drawn such as strongly represented countries or the most represented types of applicants. The text passages on the other hand hold potential for analyzing buzz words, to find for example new emerging topics in the targeted technology area. It results, that patents offer many aspects to analyze on its own, but also enable to consider multiple aspects in one context, which extends the possibilities to draw valuable insights into industries.

In each of the four following cases, different data science methods are applied. These are simple methods for counting individual pieces of information or for linking them. Following, various visualization techniques are used to present the results. This includes besides classic representations such as histograms or bar charts, network analysis that not only enable to show the frequency of individual elements, but also the link between elements in the form of nodes and edges. Therefore, the relationship between specific elements can be investigated. Through the usage of different methods and patent information in each case, various insights are generated that enable to understand a unique part of the business environment. Since the analysis of unstructured data requires a deeper insight into the subject area of data science, the following cases are mainly focused on the analysis of the structured parts of the patents.

3 Case studies

3.1 Tracing research efforts in the field of antibiotics

Alexander Fleming's discovery of penicillin in 1928 is one of the most prestigious milestones in the history of medicine - or even modern science. Based on his initial discovery, the development and industrial production of penicillin-related antibiotics enabled the efficient treatment of bacterial infections, which, at that time, would often lead to death (e.g. through sepsis) (Mutschler et al., 2001). Even though Fleming conducted his experiments almost a century ago, the treatment of bacterial infections still remains a current challenge due to the rise of antibiotic resistance in certain bacteria. Solely in the European Union, infections caused by antibiotic resistant bacteria amount to approximately 33,000 deaths per year. Nevertheless, the annual number of new broad-spectrum antibiotics has been continuously decreasing, and more and more pharmaceutical companies have announced that they are going to stop, or have already stopped, their research on antibiotics (NDR, 2019). The result is a market failure of serious consequence.

Against this background, we set our first case study and aim to trace the research efforts for β-lactam antibiotics - the biggest group of broad-spectrum antibiotics – in recent years. Thereby, we want to focus on two specific aspects:

1. How has the research efforts for β-lactam antibiotics developed?
2. Who are/were the active actors in this field?

To answer these questions, we used simple visualization techniques on a dataset of 872 patents, which were extracted from PatentsView, a platform that provides data from the US Patent and Trademark office. By plotting the number of submitted patent applications throughout the years, the severity of the research reduction becomes immediately evident (Figure 1). While the late 1980s and early 1990s are marked by constant patent applications in the field of antibiotics, the number of patent applications register a steep drop after 1993. This development indicates that research for new β-lactam antibiotics have become unprofitable for major pharmaceutical companies in the mid to late 1990s (Katz et al., 2006). To further investigate this assumption, it is worth to differentiate between the most important subgroups of β-lactam antibiotics, namely: penicillins, cephalosporins and carbapenems. In our dataset, 74% of all granted patents were for cephalosporins. This circumstance is reasonable according to the structural flexibility of this chemical compound. Because of distinct development stages, the time-dependent distributions are very different (Figure 2). Whereas the decline in patent applications for penicillins commenced very steeply in the 1980s, the decline for cephalosporins was more gradual. The application rate for patents concerning carbapenems-based antibiotics, on the other hand, increased until the early

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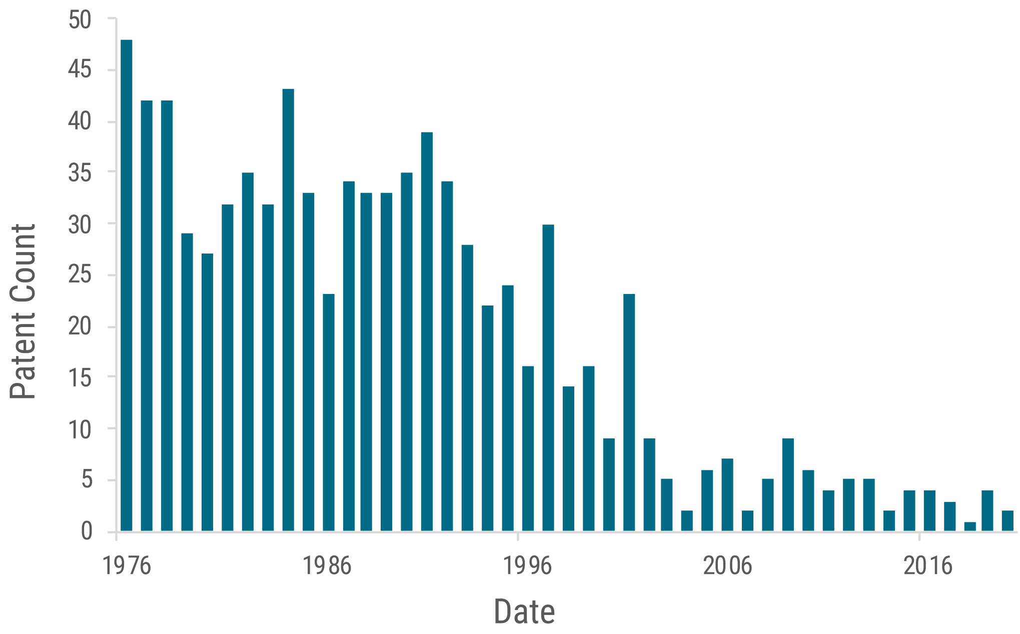

Figure 1 Number of patent applications from 1976 to 2020 (own representation).

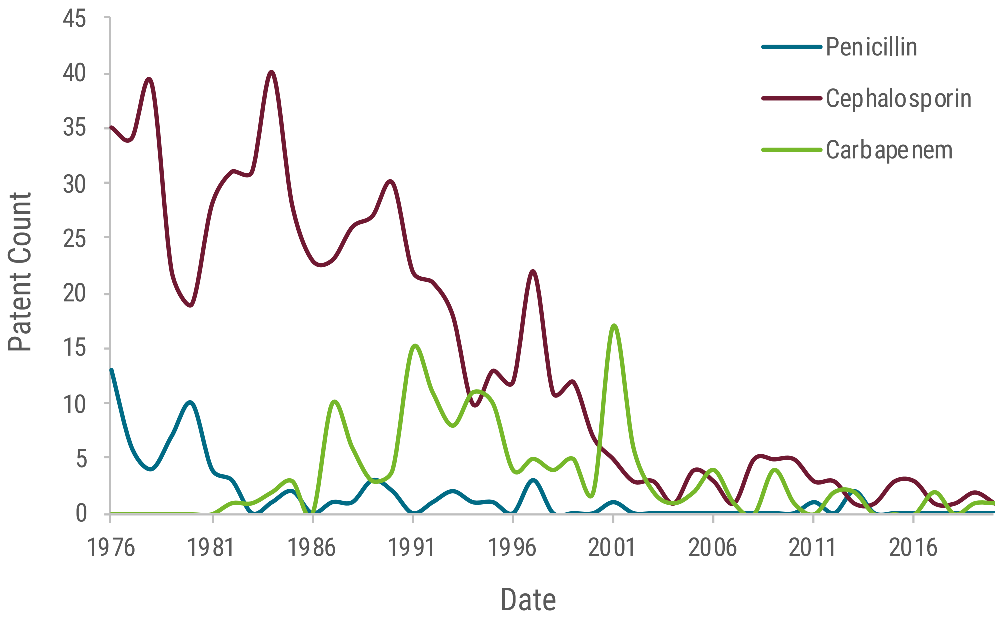

Figure 2 Normalized distribution of patents per year for each subgroup of β-lactam antibiotics: penicillins, cephalosporins and carbapenems (own representation).

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1990s and only then decreased again. These courses can be understood by the different developmental stages of the antibiotic classes. The first carbapenem antibiotics were developed in the 1980s by researchers at Merck & Co, while penicillins and cephalosporins became widely researched antibiotics as early as the end of World War II (Birnbaum et al., 1985). Nonetheless, they all converge to very low rates at least since the 2000s.

Now that we have unraveled the strong decline in research efforts concerning β-lactam antibiotics, it is worth to investigate who the actors were that developed new β-lactam antibiotics. For this purpose, we shift our focus to the patent applicants. By simply counting the number of applied patents per applicant, we can gain a good overview on the actors in this field. An excerpt of the most active applicants is given in Table 3 – interestingly, these are almost entirely of Japanese or American origin. Apart from the strong geographical dominance, there is a clear lack of universities as all of the most important actors were firms. This emphasizes the strong market and application driven focus of the research efforts in the field of β-lactam antibiotics.

Strikingly, these ten companies alone are responsible for 53% of all patents. Thereby, Fujisawa Pharmaceutical Co. and Merck & Co. have solely contributed a fifth of all β-lactam antibiotics patents. The strong decline in patent applications, however, cannot be explained by the discontinuation of research efforts of a singular firm but indicates rather a systemic development affecting most, if not all of these pharmaceutical companies. According to the analyzed patent data, β-lactam antibiotics seem to be obsolete. This finding may underline the opinion of experts who propagate new approaches beyond antibiotics (Hancock, 1997). Furthermore, so-called *blockbuster drugs* (e.g. anti-cancer drugs) hold the promise to generate much more revenue compared to medication for short-time therapy.

Taken together, in this case, we were able to shed light onto past research efforts in the field of β-lactam antibiotics. Using simple visualization techniques, we could demonstrate that research efforts in this area been declining. Furthermore, we could easily identify the most important actors. By using these easy to use steps, we were able to quickly familiarize our self with the field of β-lactam antibiotics and find evidence for the decline in research activities. The brilliant thing about data science is that once we have programmed these steps, we can easily apply them to new data sets to explore new topics. To prove this point, we use the next case to explore the field of personalized medicine.

3.2 Learning about personalized medicine

To contrast the first case, in the second case we will use similar steps to familiarize ourselves with the field of personalized medicine, starting with a short explanation. Personalized medicine (PM) is an advancing technology

Table 3 Top ten most important actors in the field of β-lactam antibiotics according to the number of granted patents (own representation).

Patent applicant	Corporate headquarters	Granted patents	Percentage share of granted patents [%]
Fujisawa Pharmaceutical Co., Ltd.	Japan	99	12,1
Merck & Co., Inc.	USA	77	9,4
Eli Lilly and Company	USA	47	5,8
Bristol-Myers Company	USA	43	5,3
Takeda Chemical Industries, Ltd.	Japan	39	4,8
Pfizer Inc.	USA	33	4,0
Shionogi & Co., Ltd.	Japan	26	3,2
Meiji Seika Kaisha, Ltd.	Japan	24	3,0
Glaxo Group Limited	UK	22	2,7
Therevance, Inc.	USA	21	2,6

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with major potential for multiple medical fields like oncology, auto-immunology and even psychiatry (Chan and Ginsburg, 2011; Davis et al., 2009). It is based on individuals' genetic and genomic information, which allows patient stratification, resulting in tailored preventive and therapeutic measurements (Green and Guyer, 2011). Hence, PM offers various application opportunities – from preclinical diagnosis, over pharmacogenomics, to molecular-targeted therapies. To foster the advantages of PM for modern health care, findings from basic research about the human genome have to be utilized and innovative products have to be developed, like diagnosis devices for disease-related biomarkers or anti-body-directed therapeutics (Chan and Ginsburg, 2011). Consequentially, PM may revolutionize the field of medicine in a similar way to Fleming's discovery of antibiotics. However, from this hypothesis interesting questions arise:

1. At which maturity stage does the technology stand right now?
2. Who is driving the research in the field of personalized medicine?

To receive a broad overview about the technology, patent titles and abstracts were searched with the general query terms "personalized medicine", "patent stratification" and "targeted therapy", rather than focusing on specialized technology within the field of PM, which may distort the results. Based on these search queries, we were able to download 589 PM patents from PatentsView. Using programmed scripts to extract specific patent indices from the data set, enables us to use quantitative approaches to trace the progression of the technology life cycle (TLC). As TLC assessment is especially important to guide strategic decision making and investments, data driven methods are useful tools to make technology's progression observable (Lee et al., 2016). There are further advantages in assessing the TLC by patent application data, because these information are accessible before product lifecycle data occur (Haupt et al., 2007). Though a single patent indicator may not provide full information about the progression of a technology, only the patent application numbers over time is showcased in this case for exemplification.

The overall annual distribution of patent applications shows a continually rise of new patents after the turn of the millennial (Figure 3). Especially the decryption of the human genome in 2002 by the *Human Genome Project* was a major milestone for the development of PM, because it offered deep insights to understand and identify important endogen factors of human health and their diversity. Based on this knowledge, further inventions and applications are developed, which result in increasing numbers of patents in this field (Song et al. 2017; Chan and Ginsburg 2011).

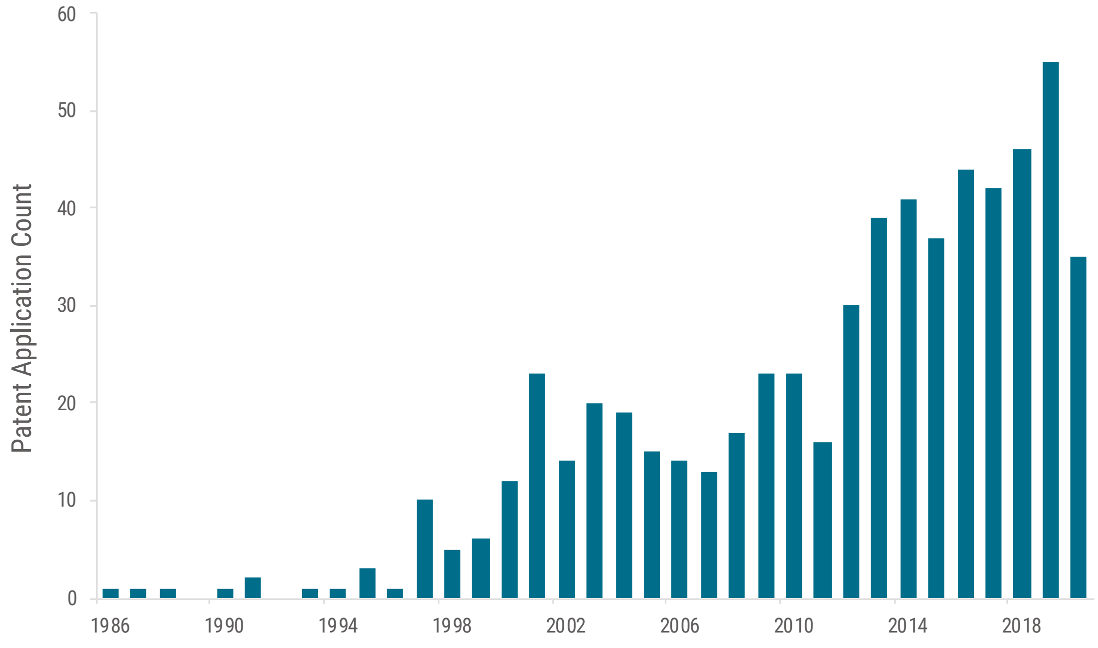

Figure 3 Distribution of patent applications in the field of personalized medicine (own representation).

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Because the annual numbers of patent applications still increase, PM has not reached the maturity stage yet, as after that, patent applications start to decrease (Lee et al. 2016). However, especially in 2006 and 2011 the trend caves in. Essential for this development are more restrictive patent regulations for genetic engineering, because genomic information is broadly classified as "natural phenomena". Therefore, related inventions are more difficult to receive a granted patent status and even some already granted patents lost their protection status (Chan and Ginsburg 2011; Holman 2015). This might lead to more reserved development of PM by the industry and might slow the overall progress and maturity, as it was observed that the strength of patent protection historically had an impact on the development of the pharmaceutical industry of different nationalities (Achilladelis und Antonakis 2001).

To attain further insights of PM's current TLC stage, the cumulated patent applications were plotted over time as well (Figure 4). Like the TLC, cumulated patent applications follow an S-shape curve as well, with slowly increasing patent application numbers of basic innovations at the introduction stage, followed by more rapidly increases when the growth stage is arrived, and later patent applications decline when reached maturity (Haupt et al. 2007). Comparably to the annual application numbers, the cumulated ones rise. At the beginning, the trend increases relatively slow which seem to turn around the year 2012, and a more rapid growth is observed. Therefore, PM seems to have reached the early growth stage. Consequentially, we can expect an increasing amount of innovations stemming from the area of PM to penetrate the market in near future.

To gain a deeper understanding of active actors in PM research, we analyzed the individual patent assignees and their number of patent applications. A more detailed look at the assignee organizations revealed that six applicants from the top ten are from academia (Figure 5). Particularly in the US, universities increasingly rely on financing from non-governmental sources to fund their research, like contracts with companies from the industry or spin-offs (Mohrman et al. 2008). Especially new and promising findings from basic research result in rising investments from the pharmaceutical industry into external knowledge (Toole, 2007). So, patents offer opportunities for universities to acquire funding. After a period of waiting and observation of developments from academical research, pharmaceutical companies invest again – this time into internal R&D (Toole 2007). The combination of organizations from academia and industry represented in holding most of the patents leads to the interpretation that the field of PM shifts from basic to more advanced technologies and gains momentum on the market, which supports the previous findings regarding patent activities (Chan and Ginsburg 2011; Haupt et al. 2007).

In conclusion, the technology of PM seems to be evolved from the first stage of introduction to early levels of growth. This might support managerial decisions to start scoping specialized fields of PM for early adoption and differentiation. However, since the technology yet seems to be transitioning between the stages, more patent indices for TLC assessment should be explored for a more detailed observation, so e.g. investment decisions like make- or buy-strategies are able to be made more solidly.

Similar to the first case, this case showed that we were able to gain insights into the current state of the technology life cycle within the field of personalized medicine using relatively simple data analysis measures. While these insights can already provide valuable information about specific technology fields or research topics, more advanced visualization and data science techniques enable us to gain much more detailed and decision-supporting insights – which we will explore a bit more in our next application case.

3.3 Dissecting innovations in the field of lithium-based batteries

For our third case, we leave the realm of medicine and focus on another transforming technology field: energy storage. The path towards a renewable and electric future is marked with many technological barriers. Developing modern battery-technologies plays a key role for future energy infrastructure. Batteries are used in stationary applications like the storage of solar or wind power, as well as in mobile applications, like portable electronics or electric cars. Especially the electrification of mobility is a strong driver for the development of new and powerful battery technologies and will lead to a sharp increase of their demand (Thielemann et al., 2018). Therefore, batteries represent a lucrative future market, however, it is a market with a lot of competition. Moreover, the battery market is very complex, because of the various applications and types of batteries. As a result, various globally distributed companies stemming from different branches are part of the market. Especially

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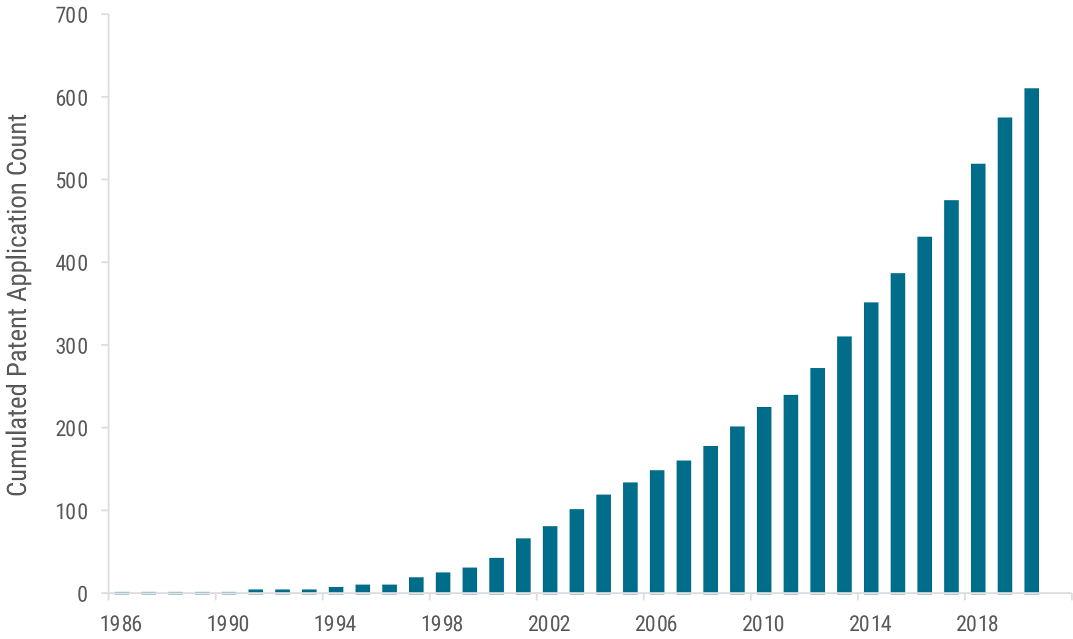

Figure 4 Accumulated patent applications in the field of personalized medicine (own representation).

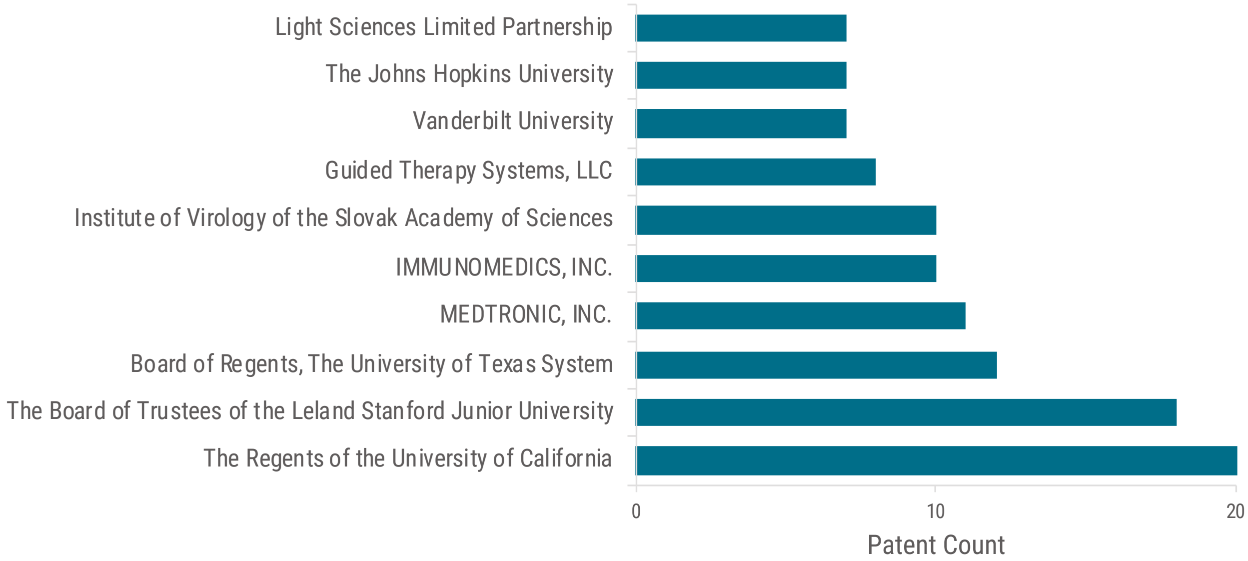

Figure 5 Top ten patent assignees in the field of personalized medicine (own representation).

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in complex technology markets, like the battery-market, a comprehensive patent-analysis can provide important and beneficial knowledge, for example about the competitive landscape. Implemented as a powerful addition to other market analysis techniques it can portray technology trends, reveal market niches, and give insights about the technological strength of competitors. Here we focus on the questions:

1. How is the battery market divided and which applicants hold the most patents in the areas?
2. What elements gained importance over time?

We focused our search on lithium-based batteries, because they are currently and in prospects the most promising battery-technologies (Scrosati and Garche, 2010). In the following two analyses are presented exemplary, to demonstrate the utility of patent data for a competitive market and technology analysis. In one analysis, using a title-word-search, we investigated the distribution of patent applicants on the battery main components (Figure 6).

Generally, it can be observed, that the electrolyte is with over 1300 patents the most examined battery component, followed by the cathode (approx. 500 patents) and the anode (approx. 300 patents). With not even 200 patents the separator is investigated the least, indicating that it is the component with the lowest optimizing potential. Despite being a central element of the battery, the electrolyte-research has been neglected for a long time (Placke et al., 2017). Now with rising importance of high-performance batteries the electrolyte is analysed more extensively and market oriented, which is visible in the high patent numbers. An important research area is for example the development of solid electrolytes for solid-state batteries (Xiao et al., 2020). The big majority of patent holders are companies, which indicates highly market-oriented research. Especially the Lithium-ion battery (LIB) is on the market for several decades and exceeded the point of basic research. Big companies like Samsung possess over more financial assets than for example universities, which eases the patent application. Furthermore, patent applications are not common at many universities and are often not profitable (Geuna and Nesta, 2006).

To further specify the technology analysis, we did a keyword-search in the patent abstracts for typical elements (despite lithium) and substances in lithium-based batteries, to observe the significance of specific substances in current research and development efforts (Figure 7). The extracted elements were assigned to the corresponding applicant and the visualisation of these connections enables to create a

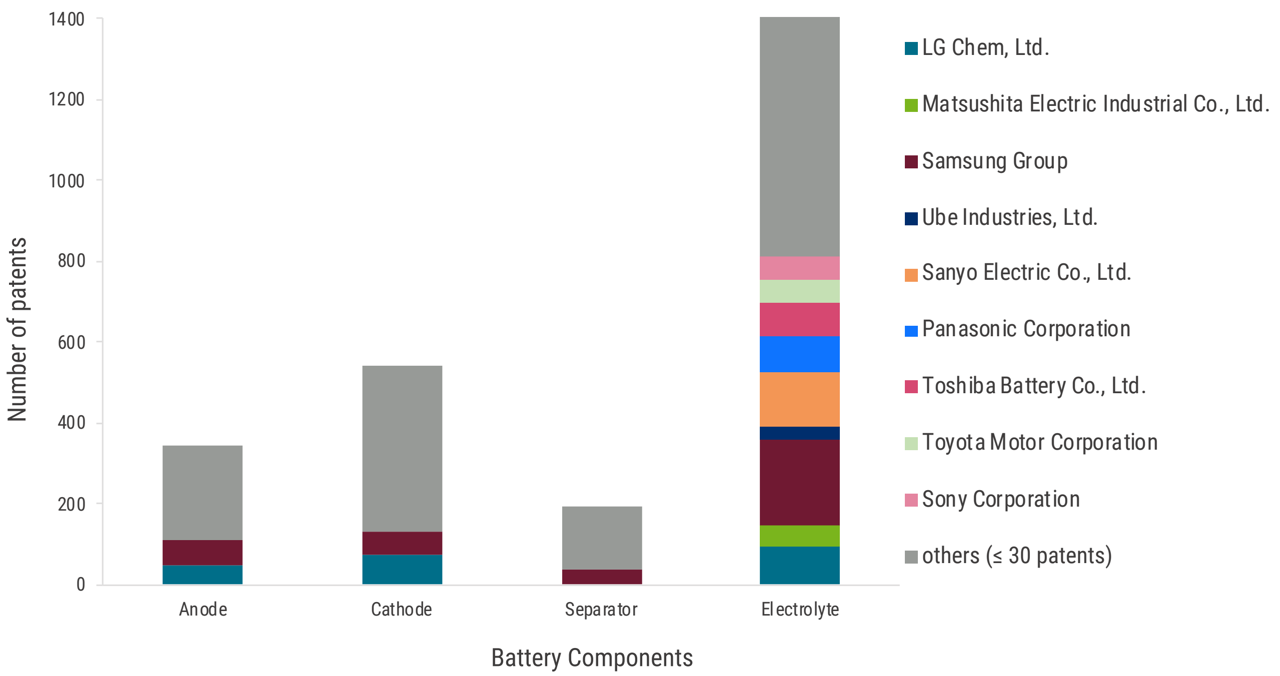

Figure 6 Number of patents concerning the main battery components, differentiated by patent applicants (own representation).

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network that represents the relations between applicant and element. In it the nodes represent an applicant or an element and the connections or respectively edges represent the relation between them. The size of the nodes and edges is proportional to its occurrence. Besides the occurrence, network specific grid centrality values are used to investigate how dominant certain nodes are in the network. These values consider the amount and intensity of connections from a node to all other nodes in the network. To recognize changes and illustrate trends, we divided the patent landscape into the three time-periods 1976-2008 (Figure 7a), 2009-2014 (Figure 7b) and 2015-2020 (Figure 7c).

The increasing significance of batteries and the rising size of the patent-landscape can be abstracted from the development of the network size. With 341 knots (10 substances + 331 patent applicants) the current six-year period (2015-2020) more than doubles the size of the previous periods, despite the first periods longer time scale and the fact that 2020 is not finished yet. We investigated ten substances on their significance in terms of patent numbers. Conspicuous is, that for all three periods nickel is the substance with the highest number of patent issuances. An explanation is, that nickel-rich, high-energy cathodes are promising materials to develop LIBs with a high energy density (Xu et al., 2017), which are especially needed for electric cars. An interesting development can be observed for the anode-materials graphite and silicon. While in the first period graphite is ranked second after nickel, in the two following periods it is dropping to place eight and seven of the ranking. Graphite anodes are cheap, technologically mature and show a high cycling stability (Wagner et al., 2013), therefore they are currently implemented in nearly every LIB. The fact that their development is already very advanced can explain the declining significance as a research object and be an indicator for companies to avoid new investments in graphite-anode-research. The contrary development is visible for silicon. In the first period it is only positioned on the 8th place of the ranking. In the following two periods the number of patents is doubling respectively, and silicon ranks on the places three and four. Silicon is viewed as a promising future anode-material, for example the development of silicon-graphite-composite electrodes can lead to higher specific capacities compared to conventional graphite-anodes (Zuo et al., 2017). By examining the networks, the high patent numbers and the rise of silicon-research can mostly be allocated to increasing research activities of only a few companies, in particular Samsung, Panasonic, Sanyo and Sony. Generally, the networks vividly illustrate, on which substances specific companies are focussing their research, which eases an overview on this complex market. Thereby specialists, who focus strongly on one substance, like Toshiba on titanium can be distinguished from companies with a broader and more diversified research portfolio, like Samsung or Sony. Moreover, it is conspicuous that iron, for example part of the cathode in lithium iron phosphate batteries, has the highest grid centrality of all substances in the second and third period, but only an average number of patents. So, iron has the highest number of connections to different companies, but most companies only hold a small number of patents. A possible explanation could be that the research of the low-cost and abundant element is very diverse and leads to several different applications (Wang et al., 2012; Yabuuchi and Komaba, 2014). Since there is no big player, who is dominating the research yet, this could be an opportunity for companies to take advantage of this gap and invest in iron-based battery research.

The two analyses showed possibilities to structure, categorize, and quantify complex technology markets. Next to showing technology and research trends, especially the product and research portfolio of companies and competitors can be thoroughly analysed, deriving recommendations for specific actions and investments. As a result, insecurities about the technological strength of competitors and of own research-investments can be minimized.

3.4 Patent analysis of stem cells

In our last case study, we focus on interactions in a legally controversial area that is stem cell research. Stem cells are body cells that can develop into different cell types and have regenerative properties (Shen et al., 2004). The application of stem cells in human medicine promises the treatment of diseases like cancer, diabetes, or neurological diseases (Kim and De Vellis, 2009; Volarevic et al., 2011). Despite their broad applications and promising treatment options, stem cells are a much debated topic to their production. The most interesting stem cells for research are embryonic stem cells, because they are pluripotent and thus can develop into all cell types (Fernandes et al., 2009). However, these must be taken from embryos and then propagated in cell cultures (Richards et al., 2004). This led to ethical debates, which finally resulted in laws on the handling of stem cells in Germany, the USA and other countries. Based on these developments, the following two questions arise:

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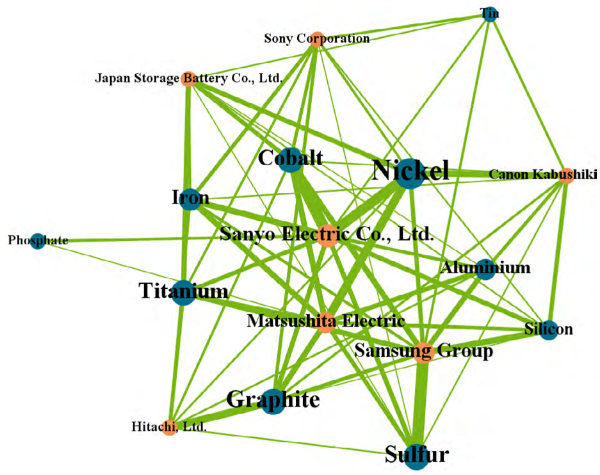
Figure 7 Correlation of substances and patent applicants, illustrated in networks and tables of network-metrics for the time periods a) 1976-2008, b) 2009-2014, c) 2015-2020. Only patent holders with at least 30 patents are shown (own representation).

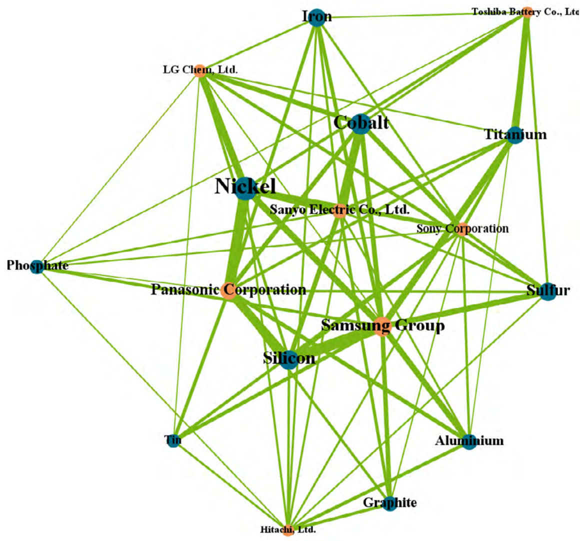
a)



Knot count (total network): 168

Substance	Patent issuances	Grid centrality
Nickel	172	0.381
Graphite	127	0.321
Sulfur	126	0.315
Cobalt	122	0.250
Titanium	119	0.292
Iron	94	0.262
Aluminium	83	0.226
Silicon	73	0.185
Phosphate	37	0.107
Tin	34	0.113

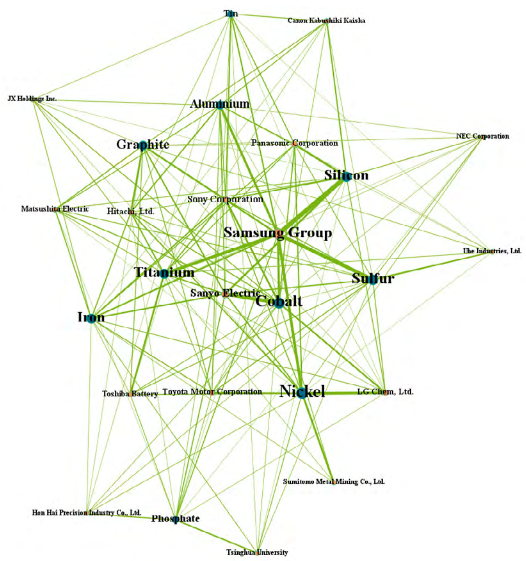
b)



Knot count (total network): 156

Substance	Patent issuances	Grid centrality
Nickel	203	0.359
Cobalt	166	0.333
Silicon	148	0.314
Sulfur	130	0.269
Iron	128	0.378
Titanium	119	0.275
Aluminium	94	0.25
Graphite	87	0.224
Phosphate	78	0.237
Tin	65	0.192

c)



Knot count (total network): 156

Substance	Patent issuances	Grid centrality
Nickel	370	0.302
Cobalt	338	0.273
Sulfur	305	0.287
Silicon	288	0.229
Titanium	288	0.267
Iron	281	0.311
Graphite	249	0.249
Aluminium	209	0.223
Phosphate	155	0.176
Tin	122	0.147

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1. Which actors have the greatest influence in the stem cell research?
2. What are the most prominent technology classes?

For the investigation of the influence of organizations in the stem cell research, we applied the network analysis similar to the battery case study, but this time connections between citing and cited patents were visualized. Therefore, the influence of an organization can be measured by investigating the extent of how often it was cited by others. Figure 8 shows an overview of the interaction of different applicants in the stem cell research field.

The size of the nodes is proportional to its citation frequency and the direction of the arrows on the edges show which organization have cited a patent from another applicant. Regarding the centrality measures, the most influential organizations of the network, which means the most cited patents, can be revealed (Table 4). From this it follows that universities such as the general hospital corporation, the university of California and the university of Illinois represent the holder of patents with the highest impact in the network. This is remarkable especially because the share of university institutions in the regarded data set is 24.44%. Therefore, this could be an indicator that universities play a central role in stem cell research. The reason for this

Table 4 Most cited organizations in stem cell research (own representation).

Organization	Citation frequency
children's medical center corporation	4
the general hospital corporation	3
university of california	3
university of illinois	3
stanford university	3

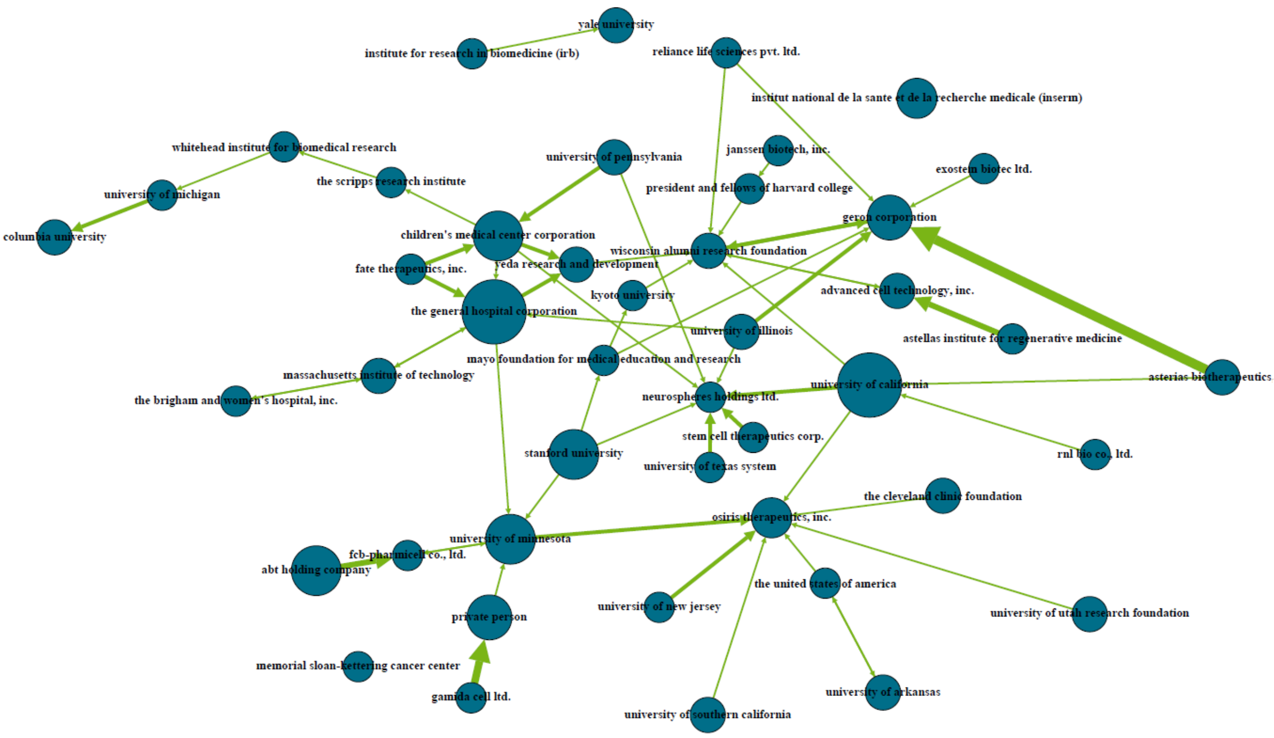

Figure 8 Representation of citing and cited patents as a network. Arrows point to the patents which were cited (own representation).

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could be the high quality of research or a specialization of universities in basic research. The focus on basic research can be further the reason for the high number of citations, as these patents could form the basis for other research projects. The situation that universities play the dominant role in the stem cell research may also result from the fact that the research field is at an early stage, which is why no or only few lucrative applications for the industry were developed yet. A Re: Journal of Business Chemistry neue Ausgabe Nummerierungen nother option could be that the government is imposing stronger regulations on research in companies and research at university institutions is partially exempt.

After finding out on which sources most patents are built, we took a look in which technology areas the most research is being done and how they are interconnected. For this purpose, the Cooperative Patent Classification (CPC) codes are investigated, which represent an extension of the IPC codes and enable insights in the most prominent technology areas in the stem cell research. Figure 9 shows a network with the most frequent CPC categories as nodes and its relations to each other as edges.

Regarding the network, five CPC classifications were highlighted through their size, which represent their frequency of occurrence in patents. Among these, the classifications a61k, a61p and c12n possess especially strong connections to each other (Table 5). This could

Table 5 Top grid centralities and co-occurrences of CPC codes (own representation).

CPC classification	Grid centrality	CPC combination	Count
a61k	0,758	a61k and c12n	1827
a61p	0,684	a61k and a61p	1802
c12n	0,642	a61p and c12n	1492
a61l	0,526	a61k and c07k	701
g01n	0,495	a61p and c07k	504
c07k	0,368	c07k and c12n	413

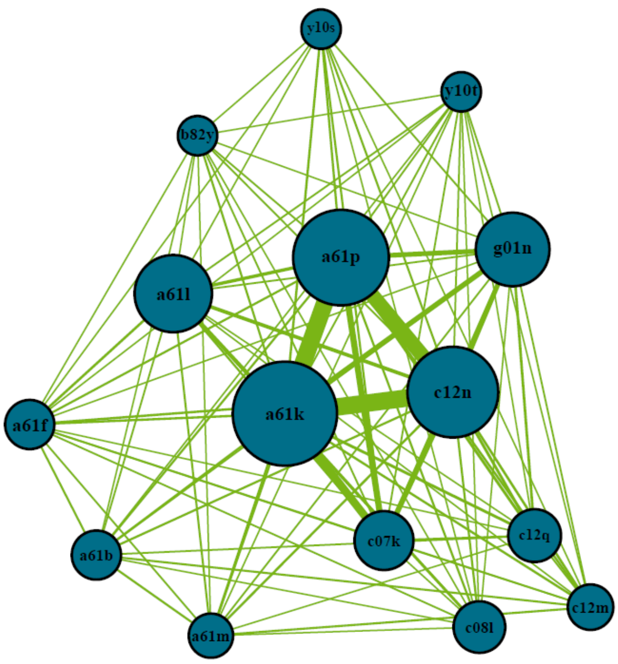

Figure 9 Co-occurrence of CPC classes in patents plotted as a networknetwork (own representation).

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indicate that these codes commonly occur together and most of the patents base on them. Therefore, it seems that the usage of microorganisms or respectively enzymes for medical purposes in form of therapies is the dominant application in the stem cell research (Table 6). Moreover, while the CPC code c07k, which stands for peptides, represent a less prominent classification in the patent data set due to its size, it possesses strong connections to the most frequent CPC codes a61k and a61p. It follows that the usage of peptides for medical purposes could be a smaller field in the stem cell area. However, this could be a hint for a growing application field in the stem cell research that will gain great importance in the future.

Through the visualization of different aspects of patent data with the network analysis the key player and key technology areas with their relationship with each other in the stem cell research could be identified. Therefore, the development stage of the research field can be estimated. This could support investment decisions due to a better understanding in how far the transition from basic research to applied research has already been proceeded. The visualization of the influence of organizations is further useful to find valuable cooperation partners or respectively acquisition targets. Moreover, by visualizing technology areas focus and emerging topics of the research field can be grasped, whereby decision makers may decide if the research field is lucrative or if there are research gaps that could be exploited.

4 Discussion

The application of data science methods on patent data from different industries showed that patent data holds a great variety of information, which allow to analyze the business environment from different perspectives. This can quickly build a data-based understanding of the environment but also allows to monitor developments in industries even with simple data science methods that can support decision making. Moreover, this article showed that patent data represent a valuable information source for companies. Analyzing information sources such as scientific publications or social media can also contribute to the understanding of the business environment. On the one hand, scientific publications hold information about the most recent research in an industry. Therefore, research trends can be grasped in an early stage, which could build the foundation for innovations and patents. Scientific publications are also similar to patents in that they must go through a review process and thus the information is thoroughly checked before publication. Thereof it results that they also represent a high-quality source of information. On the other hand, social media data could represent the social opinion on specific topics and may deliver information about trends in that area. The opinion of the society can also play an important role in many industries. Ethical concerns like in the stem cell research can hamper a field of research, although it is a promising field. This leads to consequences for future research and products. The advantage but also disadvantage of social media is that nowadays everyone is

Table 6 Most frequent CPC classifications (own representation).

CPC classification	Description
a61k	Preparations for medical, dental, or toilet purposes
a61l	Methods or apparatus for sterilizing materials or objects in general; disinfection, sterilization, or deodorization of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles
a61p	Specific therapeutic activity of chemical compounds or medicinal preparations
c07k	Peptides
c12n	Microorganisms or enzymes; compositions thereof; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media
g01n	Investigating or analyzing materials by determining their chemical or physical properties

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able due to smart devices to produce content in the internet. Therefore, a great amount of information is produced every day, but this information is not validated by anyone, whereby the quality of the content can vary. Nevertheless, it follows that multiple source should be considered to grasp different aspects of the business environment and be able to understand the big picture. However, we decided to use patent data because, apart from their information content, they offer a particular advantage to the user. The structure of patents, which consists of unstructured as well as structured parts, simplifies the analysis of this information source. Scientific publications or social media data such as tweets mainly consists of text, which represents unstructured data. The analysis of this data type is usually more complex, because texts generally have a high proportion of unimportant content. As a result, the analysis requires a lot of effort to clean the data in order to obtain high quality results. This, in turn, requires the user to engage more intensively with the field of data science. Furthermore, the interpretation of textual analyses is not always intuitive. For instance, while a word count allows easily identifying strongly represented topics as keywords in a dataset, performing and evaluating a network analysis on a text involves more difficulties. Patents, however, possess structured information that can be easily modified and interpreted without much prior knowledge, which was shown in the case studies. In addition, the wide range of information types, such as application date, applicant, CPC codes, offers the possibilities to analyze many different aspects, whereby the consideration of multiple information types in one context greatly expands the possibilities for analyses with data science methods.

For instance, the analysis of the development of patent applications over the years allowed us to get a first overview of an industry. Therefore, its maturity stage can be derived by investigating if the number of applications is still rising, stagnating, or falling. This development is a picture of the s-curve, which represents a typical course of technologies and could give evidence about how much potential a technology has left or respectively how satisfied a market is. The development can also be divided between different technologies of a market to get information about the potential of specific technologies, which was shown in the antibiotics market. This close look at a market by differentiating its technologies is particularly important to find out whether the market is generally developing positively but also whether, despite a negative development, technologies with high potential can be found in which it would be worthwhile to invest.

Combining the information of the number of patent application with names of the applicants offered us a new perspective on the patent landscape. While we figured out before how the whole industries developed, we could now find out who the key players are by analyzing which organizations hold the most patents. The type of organizations can thereby also give hints at which maturity stage a market stands. On the one hand, a strong presence of university institutions may rather represent an early stage, where the market is more focused on basic research and has no or few lucrative applications for companies. On the other hand, a strong presence of companies could lead to the recognition that the field is already well understood in the industry, which is why it has distanced itself from the basic research in universities and instead research is applied in the companies itself. Knowing who the key players are is further a necessary information to understand the competitive environment and therefore to localize valuable cooperation partners or respectively in some cases acquisition targets. Another perspective on the players in an industry can be taken by analyzing citation information from patent data. Whereas in the analyses before the strongest companies were determined according to the number of patent applications, their influence could be grasped by combining the information of citing and cited patents as well as the names of the patent holders. From this, frequently cited patents could represent patents with a high impact, which build the bases for further technologies. This impact is afterwards attributed to the patent applicant and could also give evidence about the maturity stage of the technology. As we have seen it in the stem cell research case, a high influence of university institutions could point to a strong presence of basic research. Furthermore, frequently cited patents reveal where most high quality and trend-setting knowledge in this area is available or respectively is generated, which are important strategic information for companies.

However, the patent analysis not only enable to reveal the key players in a whole industry, but also to break down complex industry environments, whereby organizations can be allocated to specific segments. This was shown in case 3, where the battery market was analyzed. We had the opportunity to analyze, which organizations dominate the whole battery market, but we divided the market by the battery components. Therefore, on the one hand the distribution of

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the companies in the industry could be visualized, whereby electrolytes were revealed as the most prominent segment. On the other hand, for each part of the industry the specific competitive environment could be investigated. Depending on which segment a company is targeting, direct competitors and cross-segment cooperation can be localized. Following, analyzing patents with data science methods enable to reduce complex industry structures, what makes it possible to get a better understanding of the environment through a more detailed overview.

Here, data science enables to combine different information, whereby various contexts can be investigated. Aside from the ability to view different pieces of information together in a new context, data science also offers the ability to present these analyses differently. Therefore, this also allows results to be viewed from different angles, expanding the possibilities for evaluation. Visualizing the organizations with the most cited patents as a ranking has the advantage that quickly the most influent ones can be highlighted. However, by plotting the results as a network, such as in the stem cell research case, the way we look at it changed. It enabled to see besides the most cited patent holder, the interactions and therefore the relations among them. This results in an ecosystem, which present the environment of companies. The monitoring of this ecosystem over time can represent changes in the environment of a company and therefore give an overview how relations among organizations emerge, change, or disappear. This procedure can also be applied to other cases in order to investigate other types of relations, such as the relationships between technology areas in form of CPC codes to investigate how they are related to each other. Here, data science again shows its advantages by making it possible to analyze multiple attributes in one context. This allows to investigate connections of varying complexity. Analyzing single attributes such as citations showed us which organization influenced another one. The analysis of linkages between two different attributes like chemical elements and organizations like in the third case offered new insights. In that analysis the usage of prominent chemical elements in the battery industry was the focus. On that basis, companies can be compared to each other, which sheds new light on the competitive environment. Depending on the focus of the company, various types of interactions in the environment can be investigated.

The high information content and analysis potential of patents are the reason why many different advanced analysis approaches have been developed over time to gain more and better insights into the business environment. Aaldering et al. (2019) developed a patent-based approach, which aims to assist R&D efforts by predicting technological knowledge interaction trajectory. This approach uses the network analysis to identify and quantify links between interacting technological knowledge areas in form of IPC codes. Based on that analysis link prediction technique is used to predict emerging, decaying and changing relation between knowledge areas in the future. Aaldering and Song (2019) extended this approach by also analyzing the descriptive text passages of the patents. Descriptive parts of patents can define knowledge areas more precisely than IPC codes by using technical terms. Therefore, they could extract the exact application fields of different battery technologies such as vehicles, devices, energy storage and computers, whereby new findings about the trajectory of application-oriented research could be gained. While most of the technological information of patents is found in the texts, their analysis offers many new possibilities. For instance, Wang et al. 2010 applied text analysis methods to derive information about future trends from descriptive text. In contrast, Yoon et al. (2013) created a text analysis approach to build dynamic patent maps, which reveal information about competition trends and technological developments. Finally, patent analysis represents a highly researched field, since its diverse information content allows the application of many different methods. The popularity of this analysis also stems from the fact that the complexity is variable. As this article showed, patent analysis can be performed quite simply to obtain strategic information. However, by combining different complementary methods, the analysis can be made arbitrarily complex to obtain even deeper insights into the corporate environment.

5 Conclusion and limitations

Although we only scratched the surface of data science methods here, we were able to gain deep insights into various industries. These simple methods enabled us to quickly build up an understanding of developments in the industries. Thus, we were able to analyze the markets from different perspectives without much prior knowledge. One of the biggest advantages of data science is that once the methods were developed, they can be applied on every data set without much effort. This makes it easier to monitor developments in the patent landscape so that an understanding of the environment and potential changes

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or respectively trends can be built. Also, companies can increase the quality of their decisions by leveraging data, as well as make strategic decisions with some foresight. Remarkable is that these knowledge could be derived by only analyzing patent data as information source. This means that important strategic information, which could grant competitive advantages is freely available for anyone. In addition, the simplicity and efficiency of patent analysis was made clear in this article. For these reasons, an awareness for the possibilities that arise from data science methods and the growing amount of free available data must be created in companies in order to understand the increasingly complex environment and to survive in the future.

Even though patents have been presented here as a valuable source of information, this type of data has certain limitations. It must be considered that not all inventions were applied as patents. Some are kept as company secrets because the inventors do not want to reveal their invention. Also, international differences in patent law hardens the comparison of patents from different places. This is also leading to a different acceptance of patent applications. At last, it must be considered that there is a delay in time between the application and the acceptance, which results in a distortion of the actuality. Despite these limitations patent analysis plays nowadays an important role for decision-making in many companies, which will probably gain greater importance in the future.

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