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Abstract

Innovation is a key enabler for industrial symbiosis (IS) between actors in a system where the waste from one actor can be used as input in another actors production and thereby create mutual benefits for each actor and the system as a whole. However, developing IS might be challenging for firms, as it requires capital investments, regulatory incentives and cooperation. To increase our knowledge on the development of IS, this chapters uncovers IS drivers and barriers between firms in Mo Industrial Park through a decade. We find that developing a circular industry is a long-term process which requires open innovation efforts where academic institutions are essential in mobilizing firms towards circularity. The main barrier for IS development, both in 2010 and 2020, is economy, where firms lack access to risk capital to invest in research-based circular solutions. Due to limited R&D and innovation experience, the firms also experience an initiative overload where they find it challenging to choose relevant initiatives to invest resources in.

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Driver and barriers for circular innovation; the case of Mo Industrial Park

Siri Jakobsen & Marianne Steinmo

Innovation is a key enabler for industrial symbiosis (IS) between actors in a system where the waste from one actor can be used as input in another actors production and thereby create mutual benefits for each actor and the system as a whole. However, developing IS might be challenging for firms, as it requires capital investments, regulatory incentives and cooperation. To increase our knowledge on the development of IS, this chapters uncovers IS drivers and barriers between firms in Mo Industrial Park through a decade. We find that developing a circular industry is a long-term process which requires open innovation efforts where academic institutions are essential in mobilizing firms towards circularity. The main barrier for IS development, both in 2010 and 2020, is economy, where firms lack access to risk capital to invest in research-based circular solutions. Due to limited R&D and innovation experience, the firms also experience an initiative overload where they find it challenging to choose relevant initiatives to invest resources in.

Key words: *industrial symbiosis, innovation, drivers and barriers, industrial park*

Introduction

Circular economy (CE) – The concept of closing material- and energy loops to extract its utilization has started gaining momentum as a solution to address sustainable development. Through the replacement of a linear model of production, where goods are manufactured from raw materials, used and disposed (Saavedra et al., 2018), the circular system maintains the value of resources, products and materials in the economy as long as possible (Merli et al., 2018). CE can be defined as *"..an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow*" (Korhonen et al., 2018, pp. 39).

Several authors argue that the CE transition needs to be interpreted at three levels (e.g. Fang et al., 2007, Sakr et al., 2011, Jackson et al., 2014); changes in social and economic dynamics at a *macro* level, implementation of circular processes such as product design and consumption at the *micro* level and industrial symbiosis between firms at a *meso* level (Merli et al., 2018). Adapting the meso level, this chapter explores a key strategy for CE; *industrial symbiosis* between actors in an industrial park, where the aim is to create physicals links between actors through the exchange of energy, materials, water and by-products (Hardy and Graedel, 2002, Prosman et al., 2017). Industrial symbiosis is found to be more sustainable than most other manufacturing concepts because they comprise more innovation targets and mechanisms (OECD, 2009, Geissdoerfer et al., 2017). This chapter keys into this debate of *change* (Damanpour, 1991), as an important attribute of innovation for IS. The change towards IS development represent a various set of barriers and drivers as they require cooperation between actors, capital and intellectual input. Numerous drivers and barriers of industrial symbiosis are recognized in literature, mainly capturing technical aspects, such as water treatment, optimization models and product flows (Bacudio et al., 2016). This chapter respond to calls for examining IS from a social science point of view (Lindkvist and Baumann, 2014), and for longitudinal case-studies on the development of drivers and barriers in IS (Zhu and Ruth, 2014). Hence, we address the following research question: *How has the drivers and barriers for IS developed in Mo Industrial park through a decade?*

We start with a theoretical presentation of drivers and barriers for innovation of IS, before the case of Mo industrial park and methods is presented. Next, findings of the drivers and barriers for IS development is discussed in relation to literature.

Drivers and barriers for IS development in an industrial system

Industrial symbiosis refers to energy- and material exchanges between actors located in geographic proximity (Ehrenfeld and Gertler, 1997) and was originally defined as *"Traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products"* (Chertow, 2007, pp. 12). Chertow (2007) mentions tree main connection of resource exchanges: (1) reuse of by-products as substitutes for products or raw materials, (2) sharing of infrastructure; use and organization of resources such as energy, water and waste water, and (3) common supply of services, such as transport, food and fire station. The goal of industrial symbiosis is that cooperation between actors increases the efficiency of the system as a whole, and although some of the actors in the system is less environmental, the whole system can be environmental because of the connections between actors (Ehrenfeld and Gertler, 1997).

More recent research studies have focused on the role of innovation as a tool for IS and green growth (Taddeo et al., 2017). This chapter keys into this debate by focusing on *change* (Damanpour, 1991), as an important attribute of innovation for IS. More precisely, we focus on the changes in drivers and barriers for IS in an industrial system. Table 1 highlights key drivers and barriers in the IS literature, classified in terms of economics, regulations, resources, cooperation, knowledge and technology, locations and management.

Table 1 Drivers and barriers of Industrial Symbiosis

	Drivers	Barriers
Economic	- Increased revenue (Giurco et al., 2011) - Lower input costs (Van Beers et al., 2007)	- Operational costs and revenues (Giurco et al., 2011) - Lack of funding (Bacudio et al., 2016, Li et al., 2015, Fang et al., 2011) - Insufficient financial support from banks (Su et al., 2013) - Investments in etended production systems (Van Beers et al., 2007)
Regulations	- New pollutant targeted regulations (Giurco et al., 2011) - Strong government engagement (Mathews and Tan, 2011, Zhu and Ruth, 2014) - Government-initiated policies (Behera et al., 2012)	- Environmental regulations (Giurco et al., 2011) - Inadequate public tax incentives (Su et al., 2013)
Cooperation	- Between stakeholdsers (Geissdoerfer et al., 2017) - Social ties (Zhu and Ruth, 2014)	- Lack of willingness to collaborate (Bacudio et al., 2016) - Lack of cooperation and information sharing (Golev et al., 2015, Gibbs and Deutz, 2007) - Lack of trust among locators (Gibbs and Deutz, 2007)
Knowledge and technology	- Specific knowledge that actors acquire through experience and learning of IS in their system (Boons et al., 2011) - Technical knowledge (Zhu and Ruth, 2014)	- Technological challenges (Li et al., 2015) - Lack of technology infrastructure readiness (Li et al., 2015, Costa and Ferrão, 2010)
Management	- Corporate sustainable focus in the firm (Giurco et al., 2011) - Proactive management (Geissdoerfer et al., 2017)	- Cultural changes within firms (Giurco et al., 2011) - Lack in awareness of IS (Bacudio et al., 2016, Chiu and Yong, 2004) - Lack of top management support (Bacudio et al., 2016, Chiu and Yong, 2004)
Resources	- Availability of resources (Zhu and Ruth, 2014) - Staff mobility between different industries (Van Beers et al., 2007)	- Resource scarcity (Giurco et al., 2011)
Location	- A facilitator in the system (Behera et al., 2012)	- Distances between companies (Giurco et al., 2011)

As these studies are mainly cross sectional and quantitative, calls have been made for studies that examine how IS networks grows for longer periods using complementary methods like cases studies (Zhu and Ruth, 2014). We respond to these shortcomings through a longitudinal case study of IS development in Mo Industrial park, and thereby contribute with new insights on the content of CE that remains largely unexplored (Korhonen et al., 2018).

The case of Mo Industrial Park

This study is based on a single case study of IS development in Mo Industrial Park, which is a critical case to understanding the IS development between actors in a industrial system (Flyvbjerg, 2006). We aim for insights on this one case in-depth and over time, rather than generalizing beyond this case,

Mo Industrial Park (MIP) is located in Mo I Rana; a city in northern Norway, capturing about 108 companies and 2500 employees, and has a total turnover of 7,5 billion (whereby 5,5 billion in exports). Steel production has been the dominant industry in the industrial park since its establishment in 1955 (as AS Norsk Jernverk), but also a variety of other companies such as maintenance and civil engineering solutions, ICT and accounting, engineering and architecture, aquaculture, logistics and special waste storage, and handling and transport. The industrial park concept is based on the individual companies concentrating fully on their own business ideas, but shares infrastructure and services with other firms in the park.

This study is a longitudinal analysis of interviews with the main actors of the industrial symbiosis in Mo industrial park as the main source (see Table 2). The interviews are conducted in 2010 and 2020, providing a unique opportunity to map both the physical changes of IS, and firm drivers and barriers associated with them. We have also interviewed external actors relevant for the IS development. In 2010, these mainly represents governmental actors and in 2020, knowledge actors were the most important. The interviews were conducted at the informants' offices and lasted for about 45 min. To uncover critical drivers and barriers of IS development, we showed the informants the IS overview (Figure 1) and encourage them to freely reflect upon the development and changes from 2010-2020 (Patton, 1990). We also used a semi-structured interview guide to help the informants to reflect on critical IS changes (Yin, 2013). Secondary sources, such as press articles, presentations and industry conference participations are used for contextual understanding. We followed an inductive data analysis approach, where both authors coded the data to unsure shared meanings (Miles and Huberman, 1994). Firm names are visible with acceptance; however, firm quotes are labeled "firm informants" to secure informants' privacy.

Table 2. Data collection

Actors	Characteristics	2010	2020
Celsa Armeringsstål AS	Produce steel reinforcements, where iron- and steel scrap is the most important raw material. Production capacity: 1,5 million tons pr. year	Size: 294 Ownership: Celsa Group (Spanish) Informant(s): CEO Environmental manager	Size: 315 Ownership: Celsa Group Informant: CEO
Vale Manganese Norway AS (2010) Ferroglobe (2020)	Produce ferromanganese with a capacity of 120.000 tons pr. year.	Size: 80 Ownership: Vale Mangenese Norway (Brazilian) Informant: CEO	Size: 91 Ownership: Ferroglobe (Spanish) Informant: CEO
Ruukki Profiler AS	Manufacture basic metals and fabricated metal products	Size: 110 employees Ownership: Ruukki Profiler AS (Finnish) Informant: CEO	Closed down in 2010
Fesil Rana Metall AS (2010) Elkem Rana AS (2020)	Produce ferrosilicon with a capacity of 90.000 tons a year	Size: 85 Ownership: Fesil Rana Metall AS (Norwegian) Informant: CEO	Size: 100 Ownership: Elkem Rana AS (Chinese) Informant: CEO
Ranfjord Fiskeprodukter AS (2010)	Produce salmon fry by utilizing waste heat from the metals producing firms	Size: 11	Size: 14

Kvarøy Smolt AS (2020)		Ownership: Ranfjord Fiskeprodukter (Norwegian) Informant: CEO	Ownership: Kvarøy Smolt AS (Norwegian) Informant: Owner
Mo Industrial Park AS (MIP AS)	Property and infrastructure company. Main tasks are to manage, develop and carry out operation of properties, infrastructure, facilities and equipment in the industrial park and adapt for new establishments and market the industrial park as an establishment location.	Size: 62 Ownership: Norwegian Informant: CEO Communication manager	Size: 67 Ownership: Informant: CEO, COO, vice president marketing
Mo Fjernvarme (CEO)	District heating company that use excess heat from the process industry as the main source (99,4% in 2020) for heat production. Produce 40 GWh.	Size: 3 Ownership: MIP AS and Helgeland Kraft Informant: CEO	Size: 4 Ownership: MIP AS and Helgeland Kraft Informant: CEO
MIP Environmental group (2010) MIP Sustainability (2020)	Coordination of environmental efforts within the park	Informant: Manager	Informant: Manager
External actors		Informant: Environment manager, Rana municipality Senior advisor, Climate and Pollution directorate (KLIF)	Informant: CEO, science park of Helgeland, Technical research institute

Industrial symbiosis in Mo Industrial park

Figure 1 illustrates the IS between firms in Mo Industrial Park in 2010.

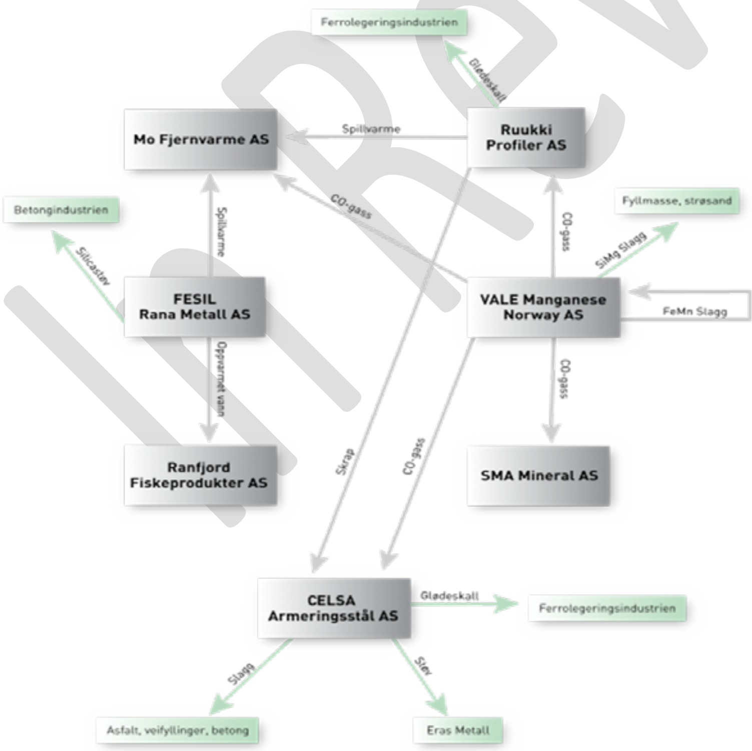

Figure 1. Industrial symbiosis in Mo Industrial park - 2010

At the core of the energy- and material exchanges are the metals producing firms; Fesil, Vale, Celsa and Ruukki, where Vale and Fesil are the largest distributors of by-products in terms of CO-gas and excess heat. The CO-gas is used as input in the production processes in four other firms within the park; SMA Minerals, Celsa, Mo Fjernvarme and Ruukki. From Fesil the excess heat is used by Mo Fjernvarme, a district heating company that sells heat to a large part of municipal- and apartment buildings. Municipal regulations demand that new buildings over 1000 square meters are connected to district heating where possible, and 80 percent of their input heat came from Fesil in 2010. In addition, cooling water from Fesil is used by a nearby salmon fry facility, where the cooling water has an ideal temperature for smolt farming. A third distributor of by-products in the park in 2010, was Ruukki Profiler, who sold iron scrap from their production to Celsa, which produce iron reinforcement from the scrap. Mo Fjernvarme also used heat from Ruukki for district heating (3 mw), although Fesil were their main heat provider. In times of very cold weather, Mo Fjernvarme used oil in addition to the excess heat from Fesil and Ruukki.

The main changes of the IS between 2010 – 2020 was that Ruukki was closed down and Celsa lost a source of high-quality and close-range scrap and Mo Fjernvarme lost a heat-source. Mo Fjernvarme has adapted to the situation and made several investments over the years to increase their percentage of renewable-energy which today is over 99 percent, but surprisingly we cannot observe many new IS in 2020, compared to 2010. However, we do observe some significant changes in the drivers and barriers IS development, as further discussed.

Drivers and barriers for IS development in Mo Industrial park

Table 3 sums up the main drivers and barriers for IS development in Mo Industrial Park in 2010 and 2020, which the following discussion refers to.

Industrial symbiosis in Mo Industrial park, 2010: "Harvesting low-hanging fruits"

Analyzing drivers and barriers for IS development, we describe the situation in 2010 as "Harvesting low-hanging fruits". This is because most of the by-product exchanges within the park took advantage of the existing infrastructure of buildings, pipelines and roads, which was built when the entire park was one state owned facility.

From Table 3 it is obvious that the main driver for innovation for circularity in 2010 was economic gains, as illustrated by an informant that explains that the they use the CO-gas (by-product from Vale) as long as it is cheaper than the alternative: *"We would prefer to use the CO-gas, but it is a financial question regarding emission trading. If the price of CO-gas and emission permits were lower compared to the use of oil, we would choose the gas. If not, we would use oil. It is as simple as that.*" This finding is in line with recent publications within the CE literature that highlight economic prosperity as the main aim of CE-activities (Kirchherr et al., 2017), and because the infrastructure for distributing the excess heat and gas is available at a low price, the firms benefit from using each other's by-products. However, further investments in extended production systems were considered a great barrier, as in line with other studies (Beers et al., 2007). The firms are reluctant to participate in long-term investments for circularity, which underlines that the role of the government is extremely important for enabling eco-industrial initiatives (Mathews and Tan, 2011). With an existing infrastructure and access to by-products, the park becomes more attractive for new establishments, which is the case of Ranfjord Fiskeprodukter that uses heated water to produce salmon fry.

Table 3: Drivers and barriers of IS development in Mo Industrial Park in 2010 and 2020

		Drivers	Barriers
Economy	2010	**About a by-product they give away for free, rather than pay to deposit:** *"It is something we do not make a profit on. It costs us to get rid of it"* (Firm informant) *"First and foremost we would prefer the CO-gas as our energy source, but it is an economic question»* (Firm informant) *"It is costly to deposit waste; if we rather make new products from it, we will make a profit"* (Firm informant) *"We can accept a lower cost-benefit-relationship if there are significant environmental benefits, but the economic investment demands are strict"* (Firm informant)	**Investment cost:** About plan for thermic power plant: *"There has been plans for this for the last 10-12 years, however, MIP [the infrastructure owner/builder] wants 30 years contracts and we cannot promise that"* (Firm informant) **SI noe mer om hvor dyrt det er**
	2020	**Quote om tilgang til kapital, og forståelsen for IS gevinster**	**Low price:** *"They are looking at alternative use of the Co-gas. To not just use it fuel purposes, but to make use of the molecules for something else. However, it is relatively low priced"* (Firm informant) **Access to capital:** *"We have proposed to add more money to the pool because I know that if we increase our internal funds and generate good ideas, we can multiply that funding… so the ambitions are high, but we are not able to follow up with enough resources. And then everything is just a little bit too weak"* (Firm informant)
Regulation	2010	**An incentive to be in front of regulations:** *"The environmental focus is much stronger from the owners than it is from the Norwegian authorities"* (Firm informant) *"They [talking about emission reduction regulations] force us to find new ways of reducing our emissions"* (Firm informant)	**Strong focus on regulations related to climate offset:** *"The paradox is that the gas we use is excess gas from Vale which should have been given free emission permits, however the government does not share our view. We actually have to pay a fee in order to recycle"* (Firm informant) **About the price of emission permits:** *"There permits are very expensive and sometimes cheaper to use oil instead. This is an economic question… If Vale has to burn their gas, it will damage the environment. However, if we have to buy emission permits, it might be more profitable for us to use propane in order to reduce our greenhouse emissions"* (Firm informant) *"..it should and shall be a shortage of emission permits in order to gain emission reductions… In principal carbon emissions have a price and firms have to start including carbon prices in their finances"* (Firm informant)
	2020	**Quote her om hvordan reg fungerer som driver i dag..**	**Quote fra noen her om press fra myndigheter …**

Cooperation	2010	**Established a environmental group:** "Quote" **Vale and Fesil was a part of a research association where Vale is part of a research project:** *"The by-product we work on in the research project will not be profitable for us to re-manufacture alone. It is therefore essential for us to be part of this association in order to develop knowledge on this"*	**Limited cooperation with actors outside the park:** *"We do not have a culture for cooperating with research institutions. We want things to go fast, and we want them to be good. That is not always a good combination. And research institutions must be trained. It takes them time to get to know our processes and problems"* (Firm informant) *"The Environmental group has not discussed the possibility of including permanent members from outside the park… I am not sure if any of the firms are interested in that"* (Firm informant) *"We have tried to get involve in environmental discussions with the industry, especially when we feel that we can contribute with something… There are challenges outside the park as well*" (Rana municipality)
	2020	**Increased R&D cooperation for circular innovativeness:** *"We believe that new establishments will come from research and development"* (Firm informant) *"I believe that we have 7-8 projects: large projects with SINTEF and such. What I am saying is that we cannot handle any more. Even though we are a small organization, we are part of many projects"* (Firm informant) *"And then we work through HighEFF in order to use the heat to produce electrical power, because then we have solved the problem. New technologies. That is one of our main motivations in HighEFF"* (Firm informant) *"We cooperate to a large extent with customers and suppliers. There is not a lot of secrecy in what we do"* (Firm informant)	**Initiative overload where firms finds it challenging to navigate and choose between several circular initiatives:** *"We have thought that because there are so many initiatives, we have to land some of them, right? Make it happen. It is new establishments we are interested in"* (Firm informant) *"It (MIP sustainability) is the program to become a world-class green industrial park. As you know there are a lot of initiatives under that umbrella, but we try to limit the number of new initiatives and rather make some of them materialize"* (Firm informant) *"In a period there where so many initiatives and requests that we were unable to handle it. It wore the process firms down that we invited them to a lot of things. They had trouble meeting up and felt that they answered the same questions over and over"* (Firm informant)
Location	2010	**Geographical proximity/ Existing infrastructure:** *"We are located here [the industrial park] because it provides us water with the right temperature from Fesil"* (Firm informant) *"The piping system [to exchange energy and materials between actors] is already there, which clearly is am advantage of being located here"* (Firm informant)	**Lack of a facilitator in the system that mobilize to IS development: Quote om hvordan mIP jobbet med IS på den tida..Kan bruke vår egen analyse fra masteroppg.**
	2020	**Mobilizing activities from knowledge actors:** *"We have worked on numerous mobilizing projects over the years, especially through a program for mobilizing research driven innovation"* (Science park)	**Consequences of Rukki's close down:** *"We had one of those heat exchangers on the roof there which obviously is out of use after Ruukki closed down"* (Firm informant)

"We have contributed to the establishment and of course we believe in it. [about establishment of local research center]" (Firm informant)	*"Because Ruukki closed down, the flow of CO-gas to Ruukki disappeared. Hence, there is only three CO-users today"* (Firm informant)
establishment of a local research center Quote	

Further, we observe that the government also plays an important part as policy maker. Environmental regulations act both as a driver and a barrier for industrial symbiosis in 2010. On the one hand, regulations motivate circular activities because firms expect stricter environmental regulations. This is in line with studies on environmental innovation which show that firms respond proactively to the expectation of future regulation (Borghesi et al., 2015). On the other hand, several firms experienced regulations as a barrier for circularity in 2010 (Moors, Mulder and Vergragt, 2005), especially regarding emission trading. They would prefer to use excess CO-gas from Vale, but they argue that due to the price of emission permits, they sometimes had to choose other (virgin) sources of energy with lower total cost.

Both circular economy and sustainability studies highlight cooperation between stakeholders as imperative to reach circular/sustainable goals (Geissdoerfer et al., 2017). In 2010 there is limited cooperation, both between actors within the park, and between actors in the park and actors outside the park, such as academic institutions, other firms or government/municipality. As the quotes in Table 3 shows, the environmental department of the municipality desires more cooperation, but the firms are reluctant to include outsiders in their internal park environmental group. Regarding cooperation with R&D institutes, two firms are involved in an industry association which conducts joint industry research, however, there are no joint research or innovation projects within the park. This is reflected in firms' production-oriented mind-set, as illustrated by one of the firm informants: *"production will always triumph research".*

Taken together, in 2010 Mo Industrial Park is characterized by taking advantage of existing win-win-situations where the exchanges between firms are initiated because they were expected to give economic profits. This would place the park in phase 1 of Baas and Boons' (2004) model for industrial eco-system development and within Chertow's Type 3 exchange where firms are located within the same geographical area, they exchange energy and materials and they have shared infrastructure. They were simply picking the fruits from governmental investments made decades before.

Innovation for circularity in Mo Industrial park, 2020: "Sowing new seeds"

Although no new symbiosis is identified in the period from 2010 – 2020, we observe some important changes in what drives innovation for circularity in 2020 compared to 2010, and the park has entered a phase of "sowing new seeds". Our data identifies several new circular innovation initiatives and an observable change in the mind-set of the firms regarding further development of the symbiosis. In this situation, the drivers and barriers for innovation for circularity are different in 2020, compared to 2010.

First, we find that the studied firms in Mo Industrial Park have put environmental and climate concerns high on their agendas and incorporated it to a much higher extent into their strategies, compared to what was the situation in 2010. An example is the overall vision of MIP AS to become "*a world-class industrial park that creates value through a focus on environmentally friendly and energy-efficient services and solutions"* (mip.no). This is also reflected in the strategies of the firms, as shown in Table 3.

With a more strategic emphasis on sustainability and circularity, we observe that the firms are much more willing to invest in new innovative circular initiatives. These initiatives originate and develop in cooperation between several actors within and outside the park. The motivation for these initiatives is a belief that circularity will increase their competitiveness. This is illustrated by the quote: *"I hoped we could be able to build competitive advantage in the process industry by initiating circular economy projects".* This attitude is quite different from what we observed in 2010, and we see that there are three important factors that influence this change. *First*, where there were practically no cooperation with academic institutions in 2010, in 2020 there are a number of R&D-projects with universities and research centers, where the most important change is the establishment of a local research center. The firms values the research center that has established circular R&D-initiatives based on firm needs, which is illustrated by the quote: *"We are starting to get "a good model" of [the* *local research center] because they understand our industry and what we need for further development" (Firm informant).*

Second, several cooperative innovation initiatives have been formalized. A key initiative to become more circular oriented, is the establishment of the innovation cluster; Arctic Cluster Team (ACT), where several of the firms within the industrial park participate to increase their innovativeness and sustainability. The initiative came from the process firms within the park and resulted in a widespread cooperation between firms and academic institutions from the whole northern region. A firm representative explains the ACT establishment: *«We were four firms at the beginning. We met and had a specific topic that we discussed each time. When Elkem entered the park they became a driver for increased cooperation and with the help from KPH [*science park*] we applied for the Arena-project* [cluster program] *which formalized the cooperation and made it bigger"*. We find that ACT has been a trigger in the strengthening of the circular mindset of several firms, which has led to a collective commitment towards circular development, as explained by one of the firm informants: "*If we are to succeed with the circular economy, we have to connect different firms and different industries. Because the solution lies across different industries."* We further observe "mobilizing activities from knowledge actors" as a driver for innovation for circularity, particular by the local science park that has worked on several initiatives towards the industry: *"We* [science park] *work with strengthening firms' competence and innovative ability, enhancing openness and trust between industry actors – they should know each other and trust each other in order to open up and cooperate on common problems"* (Science park).

Third, we observe that the infrastructure owner, MIP AS, has taken a much more proactive role in the overall development of the park, in particular on mobilizing firms in the park to develop new circular solutions. Where MIP AS in 2010 harvested the fruits of the governmental investments and took little initiative for new development, they are now coordinating several of the R&D-initiatives. One example is that MIP AS has bought an industrial area at the coast where they facilitate for new circular solutions across sectors.

Regarding the barriers, we observe that economy still is the main barrier for innovation for new exchanges. The informants highlight low prices on by-products and limited access to capital as the main economic barriers. This barrier is in line with recent research that highlights that circular-innovation initiatives require large capital investments, but as circular initiatives are associated with high risk there are insufficient financial support from banks and inadequate public tax incentives (Su et al., 2013), which calls for financial innovations for further development of the circular economy (Mathews and Tan, 2011).

Second, our data also shows the effect of losing an actor in a system. When Ruukki closed down, several material- and energy exchanges vanished, as they were both a user and a supplier of by-products. Hence, the closure of one firm effects the environmental performance of other firms in the system and they have not yet been able to replace the firm with new initiatives.

However, we observe that there are a lot of new circular initiatives, but the park seems to suffer from an "initiative overload" where the firm informants feel that they use too much time on new initiatives and less on actually putting them to life. This initiative overload could be partly explained by the firms' limited experience in R&D and innovation, where they struggle to decide what initiatives that potentially would leverage most benefits over time. Although the firms' R&D- and innovation orientation has increased significantly since 2010, the firms are still in their infancy related to their ability to develop more radical solutions, which are essential for the circular economy (Ritzén and Sandström, 2017). As such, the local knowledge actors play an important role in facilitating R&D and innovation initiatives together with the firms, as mentioned as one of the key drivers for innovation for circularity.

Conclusion and implications

By investigating the changes in industrial symbiosis in Mo Industrial Park from 2010 – 2020 we find that developing a circular industry is a long-term process which requires open innovation efforts. Here, academic institutions are essential in mobilizing firms towards circularity by involving them in cooperative initiatives to get a collective direction towards circularity. The main barrier for circular innovations, both in 2010 and 2020, is economy, where firms lack access to risk capital to invest in research-based circular solutions associated with uncertainty, and are reluctant to choose circular solutions if they are less profitable. Further, due to limited R&D and innovation experience, the firms also experience an initiative overload where they find it challenging to choose relevant initiatives to invest resources in.

To overcome the barriers of economy and limited R&D activity, we suggest that firms establish collaborations with R&D institutions and other firms to pool their resources and share the risk associated with circular innovations. Because of global awareness of sustainability and stricter requirement of all business activities to become circular, we strongly advice firms not to sit on the fence waiting for circularity to become profitable, but act now to gain a competitive advantage in a more circular future. In this process, policy makers should establish more innovative support systems for circular solutions, for risk sharing and to facilitate for cross-industry collaboration.

At last, our findings show the importance of a "proactive facilitator", such as MIP AS in this study, that facilitate and stimulate collaboration between actors in a system.

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