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Digital Platforms for Industrial Symbiosis

An Exploration of Industrial Parks in Norway

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Abstract

Industrial Symbiosis (IS) describes the mutually profitable transactions between traditionally separate industries by exchanging secondary resources and is one of the strategies in achieving a circular economy (CE). A promising role in supporting IS could be fulfilled by digital platforms, which could use the internet to facilitate economically beneficial interactions between two or more independent groups of firms (Demary & Rusche, 2018). Digital platforms can significantly reduce transaction costs on markets by serving as digital marketplaces (Berg & Wilts, 2019) and are able to form innovation ecosystems by engaging organisations to co-create products and services, fostering eco-innovation (Konietzko, Bocken, & Hultink, 2019). Despite the benefits, application in the industry is not very successful hitherto and no empirical research exists on how IS platforms can be established. This research, therefore, aims at filling this gap by finding out how to establish a digital platform to support IS among local businesses. The literature on IS, digital platforms, and innovation ecosystems are combined to investigate a minimum viable platform (MVP). Organisations operating at Norwegian industrial parks are interviewed as prospective users since no platforms are active in Norway yet. The barriers to IS, and interests and critical factors for IS platforms are investigated. Next, interviews with running IS platforms from the Netherlands provide design criteria. Subsequently, an MVP for supporting IS in Norwegian industrial parks is constructed based on the interview data. From the results it appeared that in order to reduce co-innovation risk, the identified MVP has to start with asset sharing since secondary assets can easily be administered and just replace newly bought assets in existing processes. Also, a critical mass of users is most easily secured in collaboration with existing industrial network organisations, as a large initial number of firms can quickly be affiliated and matches for the relatively standardized assets can be found within the proximity of the initial network. However, a large upfront investment is required to establish the MVP, making the IS platforms reliant on governmental support. After successfully establishing the MVP, the platform could gradually be expanded with external actors and connected with other MVPs, to eventually form an ecosystem that serves the full potential of IS. Further research could focus more on the involved stakeholders, on a larger number of running IS platforms and could extend the gained insights to other empirical contexts.

Executive summary

Digital platforms have demonstrated to successfully improve the efficiency of many markets and are, therefore, supposed to play an important role in facilitating markets for secondary materials, thereby supporting the transition to a Circular Economy (CE). Industrial Symbiosis (IS), one of the strategies in achieving a CE, exploits the potential of exchanging excess industrial resources between traditionally separate industries. Since digital platforms can connect large numbers of users, they provide the possibility to facilitate matchmaking between sellers and buyers of industrial resources. Also, platforms could allow external service providers to serve the platform users, resulting in an ecosystem fostering innovation for the CE.

However, IS platforms have not been very successful hitherto. Therefore, this research aims at finding out how to establish a digital platform to support IS among local businesses. Norwegian organisations operating at industrial parks are interviewed as prospective users of an IS platform since such platforms are not yet active in Norway. The results from Norway are complemented by interviewing already running IS platforms in the Netherlands about their experiences.

From the empirical insights, it appeared that to ensure viability, an IS platform must start with a minimum set of features, called a minimum viable platform (MVP). The identified MVP to support IS in Norwegian industrial parks is initially limited to asset sharing, because, amongst other reasons, it requires no large innovations from firms to transact on the platform, since shared assets are easily administered and just replace newly bought assets in existing processes.

Making firms willing to participate in an IS platform, requires a critical mass of users, which an MVP most easily secures in collaboration with an existing industrial network organisation, as it is possible to quickly affiliate a large initial number of firms. Access to assets is relatively standardized, which increases the likelihood of finding matches within the proximity of the initial industrial network.

Tension exists in the consideration of whom has the legitimacy to simultaneously reduce environmental impact and ensure a sustainable business model. However, since a large initial investment is required to secure a critical mass and no sufficient incentives exist for businesses to invest, the Norwegian government is needed to establish an IS platform.

The MVP could gradually be expanded with providers of complementary services, which could, by connecting multiple MVPs, create an ecosystem that serves the full potential of IS. Although the data are from Norway and the Netherlands, the insights may be relevant for other countries.

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1. Introduction

Human enterprises such as agriculture, industry, fishing, and international commerce have altered the functioning of the Earth System (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Hereby, the planet has been treated as an inexhaustible source of raw materials and an unlimited waste reservoir (Andersen, 2007). With this conception of the economy, the disturbances by the increased human enterprise exceed the capacities of the Earth System to respond, resulting in irreversible and sometimes abrupt changes to the environment (Rockström et al., 2009).

Policymakers, corporates and scientists are trying to achieve development without further pressure on the environment to preserve our current living conditions in the future. The concept of **Circular Economy** (**CE**) is increasingly used as the operationalisation of more sustainable development for businesses (Kirchherr, Reike, & Hekkert, 2017). It is a regenerative and closed system, which prevents materials from leaving the economy by restoring the value instead of disposing of products (MacArthur, 2013). Environmental impacts are reduced by minimizing the use of the environment on the one hand as a source for virgin materials, and on the other hand as a sink for residuals (Andersen, 2007).

The industrial sector is regarded as a source of environmental degradation, whereas it is also widely acknowledged that industry is essential for development and wealth creation (Azapagic & Perdan, 2000). Therefore, industry must play an important role in the transition to a CE. One key element for the transition of industry to a CE is pursuing **Industrial Symbiosis** (**IS**), which is defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow, 2000, p.313).

Although IS is actively researched for around 20 years and its economic and environmental benefits are well understood, the concept is hardly been implemented in practice (Benedict, Kosmol, & Esswein, 2018). Uncovering existing synergetic exchanges and especially implementing new ones remains a challenge (Benedict et al., 2018). A variety of identified barriers shows that it does not just entail the exchange of secondary resources, but also informational, managerial, financial, and social transactions (Benedict et al., 2018). An infrastructure to efficiently manage all these different transactions is needed to successfully implement and manage the synergies in an industrial system.

According to the scientific literature, the digitalisation of industry offers great opportunities to achieve a CE (Lewandowski, 2016). Due to technological innovations, it is now possible to monitor and track the availability, quality, and location of material and energy flows through manufacturing processes, in order to optimize the material efficiency (Antikainen et al., 2018). A promising role may be fulfilled by **digital platforms**, which are here understood as "enterprises that use the internet to facilitate economically beneficial interactions between two or more independent groups of users" (Demary & Rusche, 2018, p. 8). By applying digital platforms, the now available data on material and energy can be used to operate networked markets and can facilitate exchanges, thereby preventing resources from leaving the economic system (Berg & Wilts, 2019).

Markets for secondary industrial resources are characterized by high transaction costs. These are all costs involved in a transaction apart from the price of the product itself that prevent transactions from taking place, such as time and effort to search, quality control, and bargaining costs (Berg & Wilts, 2019). Digital platforms are able to reduce search costs by connecting large numbers of market participants through the internet, facilitating quality control and supporting efficient bargaining by providing rating and feedback systems (Lambrecht et al., 2014). Also, digital platforms allow external

actors to interact with platform users to develop complementary products, technologies, or services. The network of actors could then form a business ecosystem that supports firms to collaborate to share knowledge and information, thereby fostering innovation for the CE (Konietzko et al., 2019).

Consequently, various researchers recognize the potential of digital platforms to facilitate IS (Benedict et al., 2018; Fraccascia & Yazan, 2018; Grant, Seager, Massard, & Nies, 2010). Despite the benefits of using IS platforms, the application in the industry is not very successful hitherto. Scholars criticize current platforms for lacking crucial IS-related services and being limited to multisided markets (Benedict et al., 2018; Grant et al., 2010). Some argue that the current platforms do not serve the full potential of IS because they do not sufficiently enable innovation (Benedict et al., 2018). However, no empirical research exists on how IS platforms can be established. This thesis aims to fill this research gap by answering the main question:

'How can a digital platform support Industrial Symbiosis among local businesses?'

To answer the main research question, the research is organized along five sub-questions. The first three deal with prospective users of digital platforms for IS in Norwegian industrial parks, focusing on the barriers that are experienced with IS in general, the interests they have regarding IS platforms, and the critical factors they identify to make such platforms a success. The sub-questions are:

Sub-question 1:
What are the barriers experienced at supporting Industrial Symbiosis in Norwegian industrial parks?

Sub-question 2:
What are the interests in using a digital platform to support Industrial Symbiosis in Norwegian industrial parks?

Sub-question 3:
What are the critical factors for using a digital platform to support Industrial Symbiosis in Norwegian industrial parks?

The thesis then turns to the platform perspective to gather the experiences gained with IS platforms so far. As such platforms are not yet active in Norway, two Dutch platforms are selected to this end. Here, the sub-question holds:

Sub-question 4:
What can be learned from digital platforms currently supporting Industrial Symbiosis?

Finally, the minimum viable platform is investigated that can support IS in the context of Norwegian industrial parks, by combining the findings of the previous sub-questions. This sub-question is formulated as:

Sub-question 5:
What would be a minimum viable platform for supporting Industrial Symbiosis in Norwegian industrial parks?

The country setting of Norway is relevant, being ranked as one of the most digitalised countries in Europe (European Commission, 2019). The economy relies heavily on the lucrative petroleum industry, which is contributing largely to global climate change. With the high profits from this industry, the country is able to transform towards a more sustainable economy (Teigen, 2018).

INTRANSIT, an 8-year research centre funded by the Research Council of Norway, researches how a smarter and more sustainable Norwegian economy can be achieved (University of Oslo, n.d.). One of the research streams investigates the role of digitalisation in the sustainability transition of industries. A 3-months internship at SINTEF, a research institute that is collaborating in this research centre, supported the collection of empirical data to answer the research question.

2. Theory

2.1. Industrial symbiosis

2.1.1. Circular Economy for Industrial Systems

Kirchherr et al. (2017) have systematically investigated the great variety of CE definitions used in literature to create more clarity on the concept. In this thesis, the CE is therefore understood by the definition proposed by Kirchherr et al. (2017, p. 229):

> "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

The CE on the meso-level denotes the development of inter-firm collaboration networks to achieve economic and environmental benefits through the physical exchange of excess resources, acknowledged as IS (Ghisellini et al., 2016). To complete the definition mentioned in the introduction, Chertow (2007, p.12) distinguishes IS from less profound inter-firm relationships by setting a minimum criterion of "at least three different entities that must be involved in exchanging at least two different resources". Lombardi & Laybourn (2012), however, argued that Chertow's (2000) definition is outdated and propose a new definition that is more based on experiences of practitioners and policymakers, and describes IS more as a business opportunity and tool for eco-innovation. Their new proposed definition is as follows:

> "IS engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes" (p. 31).

Lombardi & Laybourn (2012) further argue that eco-efficiency is the result of IS because an IS network forms a fertile ground for innovation by "leveraging knowledge and resources beyond one's usual purview" (Lombardi & Laybourn, 2012, p. 12). The focus here is more on the ability of IS to foster innovation and transformation to a more sustainable industry. In this thesis, the latter conception of IS is used, as it describes the ultimate goal that is aimed for. The "mutual profitable transactions" mentioned in this definition will in the remaining be understood as either the *exchange of by-products* and the *sharing of underutilized assets*. By-products can be materials, energy and water, and assets can be all kinds of excess capacity, to be indicated together as *secondary or excess resources*.

2.1.2. The motivations and barriers for Industrial Symbiosis

Besides the environmental gains that accrue to society as a whole by achieving a CE, there are also motivations for firms and industrial parks to engage in IS. The economic reasons are most obvious because IS can yield a reduction of costs and can increase revenues through mutually profitable transactions. Also, Chertow (2007) mentions long-term resource security as a motivation for IS, by

the increased availability of critical resources through contracts. In intentionally planned industrial parks, IS is pursued in response to environmental regulations (Chertow, 2007).

Despite the theoretical benefits, both the emergence rate of new IS networks and the sustainability of existing networks are low (Fraccascia & Yazan, 2018). Some barriers to IS exist that prevent it from becoming widely adopted. Technically seen, the match between demand and supply of by-products is the most important condition for the IS synergies (Fraccascia & Yazan, 2018). A mismatch can simply occur because no firm can use a given secondary resource in its production, but also because of information asymmetry, e.g. when firms are unaware of the demand from other firms for the secondary resources they have available (Fraccascia & Yazan, 2018).
Golev, Corder & Giurco (2015) further qualitatively analysed the barriers and enablers to IS and summarized those from previous literature in seven categories (see Table 1).

Table 1. Barriers and enablers to Industrial Symbiosis (Golev, Corder, & Giurco, 2015, p. 143).

Category	*Description*
1. Commitment to SD	Organizational strategy, goals, and performance measures have to motivate managers to develop and participate in the synergy projects, contributing to the company's and regional SD.
2. Information	The detailed qualitative and quantitative data on waste streams and local industries' material/water/energy requirements provide the starting point for the development of regional resource synergies.
3. Cooperation	The cooperation and trust between key players, sharing of information, and network development are crucially important factors for new synergy projects. A coordinating body (e.g., interindustry council) can significantly contribute to this.
4. Technical	Technical feasibility is an indispensable condition to proceed with a potential synergy. A lack of technical knowledge within the industries may be an additional barrier for a new project. This can be compensated by involving a consulting company or research organization.
5. Regulatory	The uncertainties in environmental legislation and difficulties to obtain approvals for waste reuse projects from the regulatory authorities may also be an obstacle for potential synergies. At the same time, compulsory legal requirements to recycle specific materials, higher taxes for waste disposal, and so on, are the drivers for synergy projects.
6. Community	Community awareness (of the environmental and economic impacts that industries generate) can be a strong driver to initiate or stop the development of different projects. Well-established communication systems between the industries and local community, as well as environmental education programs, help to ensure the legitimate status of new synergies.
7. Economic	Synergistic connections are expected to bring a positive economic outcome along with environmental benefits. Economic feasibility may result in increased revenue, lower input costs, lower operational costs, and diversifying and/or securing water, energy, and material supplies.

Note: SD = sustainable development.

2.2. Digital platforms

2.2.1. Platform theory

Gawer & Cusumano (2014) make the distinction between internal platforms and external platforms. An internal platform describes a set of product characteristics to serve product development and innovation within a company (Gawer & Cusumano, 2014). External platforms, by contrast, have the potential to create network effects (Gawer & Cusumano, 2014). This means that the platform's value increases when it becomes adopted by an increasing number of users (de Reuver, Sørensen, & Basole, 2018). External platforms are defined by Gawer & Cusumano (2014, p. 417 and p.420) as:

> "products, services, or technologies that act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services" […] "and potentially generate network effects."

External platforms are also called industry platforms because they are managed by organisations to bring multiple firms in an industry together (Gawer & Cusumano, 2014). Some scholars describe an industry platform as a keystone in cultivating an innovative business ecosystem (de Reuver et al., 2018). Put differently, the network of firms that forms around an industry platform could potentially evolve as an innovation ecosystem, which will further be discussed in section 2.3.

2.2.1.1. Multisided and digital market platforms

When platforms mediate different kinds (or sides) of users they are called multisided platforms. Most often these kinds of users are the two sides of a market; the interaction between buyers and sellers is mediated by a two-sided market platform (Gawer & Cusumano, 2014). Gawer & Cusumano (2014) state that there are clear similarities between industry platforms and multisided markets, especially the network effects that exist when users must be affiliated to the platform to be able to interact with the other group on the market. However, while all external platforms stimulate innovation by external development, multisided markets may only facilitate trade or exchange (that is, between supply and demand as in a marketplace), which distinguishes the two concepts. The focus of this thesis will be on the concept of a digital platform, which is described as:

> "an enterprise that uses the internet to facilitate economically beneficial interactions between two or more independent groups of users" (Demary & Rusche, 2018, p. 8).

Digital platforms leverage network effects that are enabled by the rise of the internet and the development of information technology Kenney & Zysman, 2016). A great new range of economic activities is now enabled by platforms so that we can speak of a 'digital platform economy' (Kenney & Zysman, 2016).

2.2.1.2. Network effects

To understand the success of digital platforms, the concept of network effects needs to be explained in further detail. As mentioned above, network effects are generated when the value of using a platform depends on the number of other users. If the value of using the platform increases when the number of other users increases, the network effect is positive, and, if the value of using the platform decreases, the network effect is negative (Demary & Rusche, 2018). There is an important distinction to be made between direct and indirect network effects, since different groups of users are involved in a digital platform. For positive indirect network effects, for instance, the value of the platform for a user that belongs to one group, depends on the number of platform users of *another*

group. For example, for eBay, the platform's value for a buyer (one group) is increased when there are more sellers (other group) to choose from.

2.2.1.3. Success of digital marketplaces

Due to the abovementioned positive indirect network effects, multisided platforms are successful in attracting large numbers of users from different sides to get together through the platform. Digital marketplaces are a form of two-sided platforms since they mediate the interaction between on the one side 'the buyers' and the other side 'the sellers'. Digital marketplaces provide buyers and sellers with positive indirect network effects that far exceed the network effects of physical marketplaces by exploiting the wide-spread usage of internet-connected devices (Demary & Rusche, 2018; Evans & Schmalensee, 2016). Both buyers and sellers are customers from the platform since they pay the platform to use its service to access the network effects provided by the platform. As a matchmaker, a digital platform is able to aggregate large amounts of information about offered products and subsequently provide access to buyers to that data, which supports buyers to find the right match by reducing the time and effort to search for the desired product (Lambrecht et al., 2014). The other way around, sellers can reach a large number of buyers by the indirect network effects provided by the platform. Hereby, digital matchmakers are able to make matches that would otherwise be impossible, because it would have taken too much time and effort on the one hand for the buyer to find the right product, and on the other hand for the seller to find someone willing to buy. The time and effort that are saved by using the digital platform are the search costs, which, together with other forms of transaction costs, prevent transactions from happening. Evans & Schmalensee (2016) explain that digital platforms create value by reducing transaction costs, also called market frictions. The authors point out one of the fundaments of digital platforms (Evans & Schmalensee, 2016, p. 57):

> "They [digital platforms] are more valuable in total to all parties the more important the frictions they address are, and the greater their success at reducing them."

Digital platforms can reduce transaction costs in different ways. As mentioned, by lowering search costs for a certain product, a market becomes more transparent, which enables efficient matchmaking. Also, by rating and feedback mechanisms a platform can eliminate low-quality users and reward high-quality users to address trust-related frictions (Lambrecht et al., 2014).

2.2.1.4. Securing critical mass

The value of using a digital marketplace is that users are facilitated in finding matches that may not have been found without using the platform due to the reduction of transaction costs. However, for a user of one platform side (e.g. buyers) to be able to find the right match, there needs to be a substantial number of users from the other side (e.g. sellers) affiliated to the platform (Demary & Rusche, 2018). For example, when there is an insufficient number of sellers affiliated to the platform, a buyer is not able to find the right match and there is no value for him to participate in the platform. Even so, a seller will not participate in a platform when there are not enough buyers to interact with. Because of indirect network effects that work in both directions, it is hard to determine which side comes first, also called the *chicken-and-egg problem* (Demary & Rusche, 2018).

Evans & Schmalensee (2016, p.78) developed an economic model that explains how the number of participants of two-sided platforms grows or 'ignites' and shrinks or 'fizzles' (Figure 1). Suppose that group A in Figure 1 (x-axis) contains buyers on a certain market and group B (y-axis) contains the sellers. If the platform has a sufficient number of sellers affiliated to successfully match with buyers, it provides value to buyers and therefore attracts more buyers, in turn increasing the value to sellers, resulting in self-sustained growth of platform participants, depicted as the white area in Figure 1.

However, since indirect network effects work in both directions, a low number of sellers will be insufficient to successfully match with buyers, providing no value to buyers who therefore leave the platform, in turn decreasing the value to sellers, resulting in implosion or a shutdown of the platform, shown with the blue area in Figure 1.

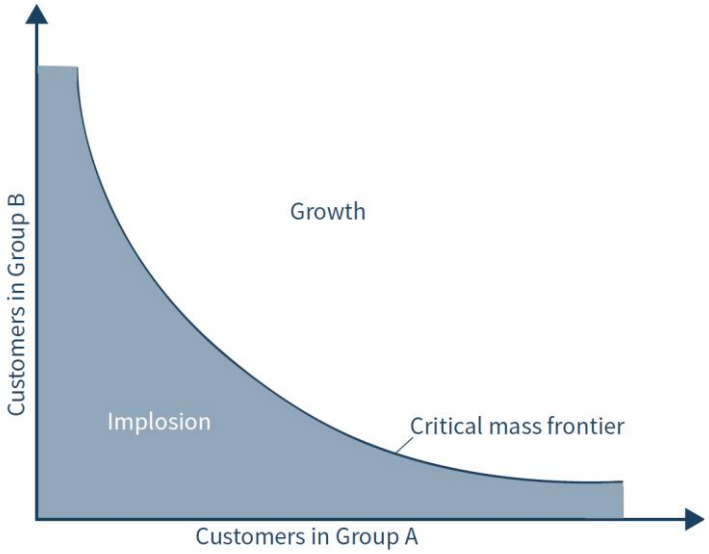

Figure 1. Critical mass frontier. Development of digital platforms with positive indirect network effects (Evans & Schmalensee, 2016, p. 78).

The success of a two-sided platform depends on securing a number of buyers/sellers that provides sufficient value to attract seller/buyers, which leads to self-sustaining growth. This number of platform participants is called the *critical mass.* The critical mass frontier, dividing implosion and growth of the platform, represents all the possible combinations of buyers and sellers that are sufficient to start self-sustaining growth (Evans & Schmalensee, 2016). It depends on the market characteristics of the product in question, where the critical mass frontier lies.

To reach the critical mass frontier, the platform needs to induce an initial group of platform users (Evans & Schmalensee, 2016). Note that in the top left of Figure 1, the number of sellers must be high to provide enough value to attract only a small number of buyers, to secure a critical mass. Therefore, a platform can strategically attract an initial number of sellers by subsidizing them with, for example, a free service. This subsidy will be paid off later when the critical mass is reached and the number of buyers ignites (Demary & Rusche, 2018). Demary & Rusche (2018) state that subsidizing is a common procedure for digital platforms.

2.2.1.5. Thick market

However, attracting sufficient buyers and sellers to a platform is not the only thing that a platform owner needs to accomplish if it wants to grow. In order to attract enough buyers and sellers to secure a critical mass, there needs to be a sufficient number of both buyers and sellers that are *willing* to get together through the platform to trade a product (Evans & Schmalensee, 2016). Evans & Schmalensee (2016) explain that a platform needs to make the market *thick*, not by just attracting more buyers or sellers, but by making sure that more sellers are attracted with whom the buyers *want to be matched with*. The authors explain that a strategy could be to focus on a narrow product range or target group to assure that participants are actually willing to transact on the platform.

2.2.2. Digital platforms and the Circular Economy

Most of the literature on digital platforms in the context of sustainability has been focussed on the sharing economy in a consumer-to-consumer context (Konietzko et al., 2019). In the sharing economy, consumers are "granting each other temporary access to underutilized physical assets ("idle capacity"), possibly for money" (Frenken & Schor, 2019, p.3). Recent literature on digital platforms extends the potential of digital platforms for a more sustainable and 'circular' economy in a business-to-business setting. Konietzko et al. (2019) describe three roles that digital online platforms can play in this:

1. Firstly, platforms as digital market places are able to mediate the exchange of goods and materials between groups of platform users, by sharing information of multiple sides of the market and thereby lowering transaction costs, as described in section 2.2.1.3. Digital platforms can potentially slow resource loops by enabling access to underutilized assets as in the sharing economy, and by creating markets for by-products.
2. Secondly, digital platforms can serve to operate product-service systems, in which customer value is created without selling ownership but through maintenance contracts that incentivise firms to invest in long-lasting products and therefore enable a CE (Konietzko et al., 2019).
3. Thirdly, digital platforms empower and engage organisations to co-create products and services, fostering innovation for the CE. Konietzko et al. (2019) explain that through online platforms "people and organisations can collaborate to share knowledge and information, repair, (re)design, own and manufacture products, components and material' (p. 444).

Notice that this distinction of three roles of platforms is consistent with the distinction of Gawer & Cusumano (2014) between industry platforms (role 3) and digital marketplaces (role 1). What Konietzko et al. (2019) add, is the possibility of using platforms for product-service systems. However, such systems are not multisided, since there is only one seller of services (to multiple clients), and, accordingly, they do not qualify as digital platforms. Nevertheless, the products being rented out by the seller can be shared among customers at different times, supported by an online reservation system that is similar to a multisided market in that a match needs to be made between a customer (one side) and the provided access to an asset (the other side).

2.2.2.1. Digital platforms and IS

Grant et al. (2010, p.741) state that ICT tools have been developed to support IS, because "IS linkages often form between companies of different industrial sectors that do not have established customer/supplier relationships and thus require communication that transcends the existing customer/supplier network". Since digital platforms have proven to be successful in reducing transaction costs, digital platforms are regarded as promising to mediate IS exchanges, as depicted by Konietzko et al. (2019) in role 1. Especially, the transparency on the market for IS could be enhanced by lowering the search costs for secondary resources. However, ICT tools are not yet successfully implemented to support all facets of IS on a wide scale. A trend from ICT tools as databases towards online platforms is described in the literature (Benedict et al., 2018). These IS platforms are developed to share information but additionally provide IS-related services, such as enhancing cooperation, participation and community awareness (Benedict et al., 2018).

From the abovementioned roles of digital platforms in the CE, two are especially relevant for the support of IS: functioning as a multisided platform to facilitate a market for resources (1) and as an engagement platform to foster eco-innovation within the industrial system (3). The second role, operating product-service systems, is not applicable in the context of IS since IS platforms do not own the means of production themselves but support the exchange of assets among industrial firms.

2.2.2.2. Barriers to Industrial Symbiosis Platforms

Based on literature research, Benedict et al. (2018) distinguish four barriers for the successful implementation of IS and the corresponding support by digital platforms.

1. First of all, the availability, quality and currency of data is a problem. IS platforms fail to facilitate manual data creation or data is not provided as it may concern confidential information. Also, large amounts of heterogeneous data are required to identify and assess IS synergies, which lack compatibility (Benedict et al., 2018). Benedict et al. (2018) argue that expert knowledge is required to interpret the data.
2. Secondly, the social aspects of IS are often neglected. Grant et al. (2010) describe a trend from ICT tools facilitating only explicit knowledge-transfer by just putting information in a database, to digital platforms that also facilitate the flow of tacit knowledge, such as social capital and trust, by investment in usability and sociability.
3. Thirdly, the functionalities of current IS platforms often reach no further than serving as a digital marketplace. The focus on the management of existing synergies and the extension of the platform with complementary functions should not be neglected when creating a lasting IS platform.
4. Fourthly, most of the platforms are difficult to access, not operational or not used (Benedict et al., 2018). The level of awareness among potential users is often too low and the platforms become static networks of resource sharing and do not attract new participants. The aim of IS platforms, however, should be to enable new and innovative synergies expanding over new industrial firms and regions (Benedict et al., 2018).

2.2.2.3. Types of IS platforms

There are different types of IS platforms being used to date. Van Capelleveen et al. (2018) describe different types of information systems facilitating the identification of symbiosis and the functional support that the systems can provide, see Table 2.

Table 2. Types of Industrial Symbiosis Platforms (Van Cappelleveen et al., 2018, p. 157)

	Name	Description
1.	“Open online waste markets”	Passively facilitates transactions of by-products.
2.	“Facilitated synergy identification systems"	Actively facilitates transactions through coordination of an intermediary.
3.	“Industry sector synergy identification”	Profiles material use per industry to detect synergies.
4.	“Social network platforms and social network communities”	Builds relations or exchange knowledge on IS experience through existing social networks.
5.	“Industrial symbiosis knowledge repositories"	Enables collaborative knowledge creation by providing a platform to share and discuss IS experiences.
6.	“Region identification system for industrial symbiosis”	Enables urban planning and policymaking by using geographical information systems that assess potential IS areas.

2.3. Innovation Ecosystems

Recall from the previous section, that industry platforms, in contrast to multisided markets that merely facilitate trade, are described as a keystone in cultivating a business ecosystem. Industry platforms serve as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services (Gawer & Cusumano, 2014). Against this backdrop, the revised definition proposed by Lombardi & Laybourn (2012, p. 31) mentioned in section 2.1 becomes relevant:

> "*IS engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes*."

In proposing this new definition, the authors reformulate the essence of IS from being about the 'physical exchange of resources' into 'eco-innovation'. The focus of IS, then, is to foster innovations among networked organisations, which will *result* in physical exchanges of resources and thereby to take full advantage of circularity. The mutual learning and information sharing in the IS network provide the conditions that foster innovation, which result in eco-efficient gains through the physical exchange of resources among firms (Lombardi & Laybourn, 2012). This conception considers IS as a business opportunity and tool for innovation, which is also adopted in this thesis.

The industrial ecosystem resulting from the IS collaboration provides an innovation-conducive environment. In literature, such an environment is called an innovation ecosystem, which, enabled by digital technologies, can nurture innovation by co-creation among the ecosystem actors. (Smorodinskaya, Russell, Katukov, & Still, 2017). Co-creation is defined as:

> "an active, creative and social process, based on collaboration between producers and users, which is initiated by the firm to generate value for customers and compete to pass others in the category" (Roser, Samson, Humphreys, & Cruz-Valdivieso, 2009; Smorodinskaya et al., 2017, p. 5247).

Digital platforms could, as external platforms (explained in section 2.2.1), serve as a foundation that allows external innovators to co-create their own innovations that complement the IS platform. As mentioned in section 2.2, Konietzko et al. (2019) describe co-creation as the third role that digital platforms can play in the CE. Because industry platforms are a keystone in cultivating business ecosystems, the establishment of an innovation ecosystem could emerge by initiating co-creation among businesses around an industry platform for IS.

Since innovation ecosystems are characterized by interconnectedness between innovating firms, the success of an IS platform depends on the different actors of the ecosystem (Adner, 2012). Adner (2012) presents a path-breaking theory on the dynamics and management of innovation systems. He argues that because of an increasingly interconnected business world, the traditional innovation strategy has blind spots. The success of an innovator is no longer focussed on his own performance but increasingly depends on the partners in the innovation ecosystem.

2.3.1.1. Co-innovation risk

One of the blind spots that Adner (2012) describes is co-innovation risk. Seeing the co-innovation risk is realizing that you are not innovating alone. Instead of considering whether the innovator itself can successfully innovate and deliver the product, the perspective should be wider by considering

whether and when other actors in the ecosystem are going to successfully deliver their own complementary innovations that are needed to make the intended value proposition reality. Assessing those risks is usually done by averaging the probabilities of success of all required complementary innovations, but in reality, it is a multiplication of probabilities. This often results in an overestimation of success, with unpredicted setbacks of innovations. Adner (2012) explains that co-innovation should be managed by carefully supporting the right actors in the innovation ecosystem: co-innovators with the lowest probability of success and the greatest value for your innovation.

Adner (2012, p.87) explains the role of an "ecosystem leader" to create an ecosystem that delivers the intended value proposition to the end user while assuring that all partners, including himself, are profiting. Sometimes this ecosystem leader needs to sacrifice to get an innovation system working; it requires that up-front investments need to be made and up-front risks need to be taken, but eventually allows to reap the rewards.

2.3.1.2. Sequencing the successful construction of ecosystems

The larger the innovation ecosystem, the more dependent the innovator's success is on innovations from other actors in the ecosystem. Adner (2012) describes that in the world of product innovation, the innovator starts with a prototype in the development stage, followed by a pilot to test the fully functional version of the product on a small scale, which eventually develops to the value proposition of the product at full scale. However, in the world of innovation ecosystems, you need to assure that multiple partners in the ecosystem innovate, to deploy your value proposition. Therefore, Adner (2012, p. 140) suggests an alternative pathway for sequencing the successful construction of ecosystems.

1. *Minimum Viable Ecosystem (MVE)*. "The smallest configuration of elements that can be brought together and still create unique commercial value." To keep the risk of being dependent on co-innovations, an ecosystem innovator should start with an MVE, consisting of the partners that are critical to creating value (Adner, 2012).

2. *Staged Expansion.* "The order in which additional elements can be added to the MVE so that each new element benefits from the system already in place and increases the value creation potential for the subsequent element to be added." The MVE provides a working basis system, to be able to subsequently expand with additional elements to eventually fulfil the complete value proposition that was originally aimed for (Adner, 2012).

3. *Ecosystem Carryover*. "The process of leveraging elements that were developed in the construction of one ecosystem to enable the construction of a second ecosystem." The success of one ecosystem can create an advantage in starting a new ecosystem by connecting or extending the value of the original ecosystem (Adner, 2012).

2.4. Conceptual framework

In the interest of society, increasing the practice of IS is important to achieve a CE. Despite their promising potential, digital platforms for IS have difficulties with becoming widely adopted and staying in operation. Several researchers describe the shortcomings of platforms in case studies and some researchers suggest templates for platform designs (Van Capelleveen, 2018; Benedict et al., 2018). However, a theory on the establishment of a digital platform to facilitate IS through digital platforms is lacking. In this thesis research, the three bodies of literature discussed in this chapter will be merged to explore the process of successfully establishing IS platforms (Figure 2).

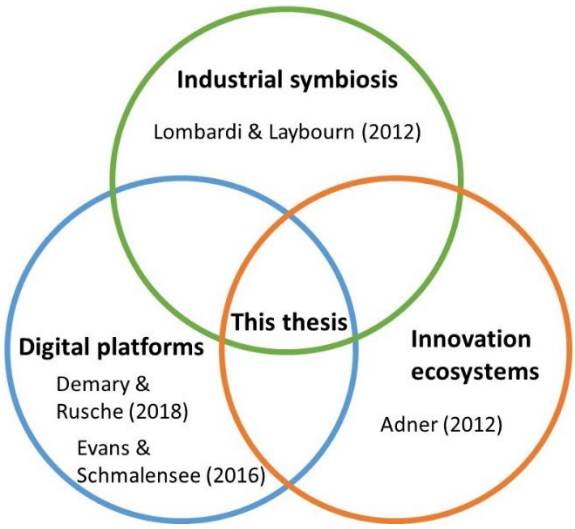

Figure 2. Position of the research within the literature that is combined.

Current IS platforms are criticized to be limited to serve as a marketplace for IS and to be unable to support innovation, though a transition to IS platforms that deliver complementary IS services is described recently (Benedict et al., 2018). Therefore, this thesis argues that digital platforms should fulfil two roles described by Konietzko et al. (2019) to support IS: providing a digital marketplace for secondary resources and fostering co-creation.

However, to establish a marketplace, section 2.2.1 explained that a critical mass of user is required. In addition, section 2.3.1.1. explains that co-innovation risk threatens the successful establishment of an innovation ecosystem by the critical dependency on other actors' ability to innovate.

2.4.1. IS Platform establishment as a step-wise process

A well-functioning platform supporting the full range of the IS domain is hard to establish as an innovation ecosystem cannot be organized from scratch. Hence, one can expect the establishment of IS platform to follow a step-wise process. In this research, it is proposed that using the interpreted "innovation ecosystem" approach to IS could result in an improved process of establishing a sustainable IS network, divided into several steps.

At first, there may be sought for a *minimum viable ecosystem* for an IS platform (MVP) that is relatively easy to design and operate, but which is not dependent on co-innovations and is able to create a critical mass, to ensure the self-perpetuation of the platform. Here, in particular, one can think of a digital marketplace with a matching function to support local businesses to exchange

information to create opportunities for IS. Once established, the platform supports the *staged expansion*, by allowing additional organisations to interact with the platform participants, to form an industrial ecosystem. This means the platform-based ecosystem poses the opportunity to facilitate eco-innovation through co-creation by allowing external organisations to provide complementary services, such as payment, contracting, quality control and logistics. Eventually, by *ecosystem carryover*, the boundaries of the IS system could be extended or connections with other platforms could be established.

The thesis that is aimed to explore holds that digital platforms can successfully support IS by following a stepwise process from a digital platform for 'matching the demand and supply for excess industrial resources' to a more advanced platform 'facilitating co-creation through creating an innovation-conducive environment'.

3. Methodology

3.1. Research methods

Before the empirical research, the aforementioned concepts and theories were studied by extensively investigating scientific literature and two theoretical books (by Adner, 2012 and by Evans & Schmalensee, 2016). Subsequently, the application of the theory in this research was proposed and approved by the supervisor and an independent second reader. As it is a novel phenomenon that is investigated, and the goal is to better understand how to successfully establish an IS platform, the research is of explorative nature. Inductive reasoning is used because it generalizes observations of supporting IS to eventually provide a step-wise process for establishing IS platforms (Thomas, 2003).

To explore the thesis posed in section 2.4.1, real experiences with supporting IS are investigated by qualitative case study interviews, since this is a method that allows to research a complex phenomenon in-depth within a limited time frame (Yin, 1998). Also, the choice for case studies is suitable for this research as it allows to analyse the novel approach in a domain where there is a great variety of organisations, relationships and other factors that cannot be controlled.

3.2. Data collection

Since IS platforms are very new phenomena, the method of data collection was dependent on the availability of cases. There were no IS platforms found in Norway, which limited the case study interviews to investigating the experiences with supporting IS and exploring the prospects of an IS platform. Additionally, interviews were conducted in the Netherlands with IS platforms already active, to complement the research in Norway with actual experiences with existing IS platforms. Therefore, the empirical research consists of two parts. The first part of the data collection investigates how digital platforms can support IS in industrial parks in the Norwegian context. Nine interviews with potential users of IS platforms were conducted in Norway, of which the results will be presented in chapter 4. The second part of the data collection concerns two IS platforms already active in the Netherlands as well as one company already using the platform. In these three interviews, the emphasis is on the design criteria to develop a viable platform. The results of this part will be presented in chapter 5. Building on and combining the findings gained from prospective Norwegian users in chapter 4 and the experiences with two Dutch platforms already active in chapter 5, chapter 6 investigates the minimum viable platform. Figure 3 illustrates how the sub-questions are divided over the two parts of empirical research and how the parts come together in chapter 6.

When possible, the interviews took place in person by travelling to the organisations' offices, but, considering the large travel distance between the internship location and the interviewees in Norway, most of the interviews took place through video meetings (Zoom). Moreover, the interviews in the Netherlands were also conducted via Zoom, because of the travel limitations due to the COVID-19 outbreak. Although face-to-face interviews are preferred over video meetings because of issues with rapport, non-verbal communications and distractions, they are a valuable alternative that poses advantages by allowing to contact participants that are far away in a time-saving and financially affordable way, thereby increasing the variety of the cases (Lo Iacono, Symonds, & Brown, 2016).

Since this research uses the approach of in-depth case study interviews, the interviews are semi-structured (Yin, 1998). The many follow-up questions and discussions, therefore, resulted in extensive interview sessions that took one to one and a half hours. During the interviews, an interview guide was used (see appendix 1) that differed between the two parts of the research (in Norway and the Netherlands). The order of questions posed to the interviewees was flexible, but eventually, all questions from the guide were covered. It is worth noting that while a generic interview guide was used, some questions were adapted based on preliminary desk research on the specific case.

As the interviews in Norway were conducted with representatives of organisations who are not yet familiar with the phenomenon of IS platforms, the interview was divided into two parts; the first part contained questions about the current state of IS. Subsequently, the interviewer explained the concept of a digital platform that could potentially support IS, and then, in the second part of the interview, questions were posed about the potential benefits of supporting IS by a digital platform. The interviews conducted in the Netherlands focussed on the experiences with the platforms to identify design criteria that are relevant for the process of platform establishment.

Before participation in the interviews, the interviewees were asked for permission to digitally record the interview and whether they could be called by name in the thesis.

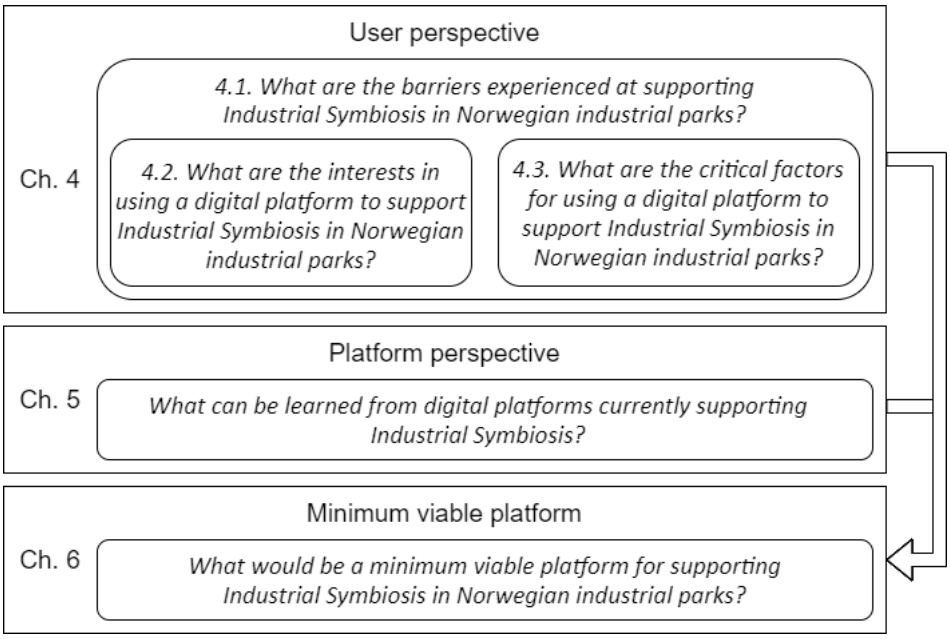

Figure 3. Structure of the results.

3.3. Sampling strategy

To select the right cases, the strategy of purposive sampling is used, which is common for qualitative research (Robinson, 2014). Based on preliminary knowledge about the subject, the cases were selected to be relevant to the research question. The units of analysis are '(potential) operators of IS platforms' to understand, describe and compare different aspects of supporting IS with digital platforms.

As explained in section 3.2, there were no IS platforms active in Norway, which led to the strategy of selecting prospective platform users in Norwegian industrial parks to research the user perspective, and selecting active platforms in the Netherlands to research the platform perspective (see Figure 3).

Norwegian organisations were selected that are operating in industrial parks with a substantial number of firms since they have the potential network that is relevant for an IS platform. Also, organisations that published ambitions concerning the CE on their website or in newspapers were prioritized, as they were deemed knowledgeable about the topic. Areas with unvarying industrial activities, such as the petroleum industry were not taken into account, as they may be less suitable for supporting cross-sectoral collaborations as pursued in IS. By doing an internship at SINTEF, an independent research organisation in Trondheim, it was possible to connect with interviewees in Norway. With SINTEF's support and complementary internet research, the organisations were approached. From a list of fifteen industrial parks that were contacted by successive email and phone calls, nine interviewees eventually responded. The platforms in the Netherlands were selected based on the availability of active IS platforms found on the internet. The two cases were the only two active platforms in the country and the one Dutch organisation is using one of those platforms at industrial parks that it manages.

The interviewees and their organisations are shortly described in the appendix 2 and 3. Table 3 provides an overview of the different cases that are interviewed and Table 4 depicts the different types of organisations and what positions the interviewees hold. In the next chapters there will be referred to the different interviewees by codes (see Table 3). The interviews with organisations O2 and O4 have been conducted with two persons at the same time, which will be distinguished by subscripts (e.g. $O2_1$ and $O2_2$).

Table 3. Overview of the interviewed cases.

Reference code	Organization	Located in	Date
Industrial organization (O)			
O1	Mo Industripark	Mo I Rana, no	12-2-2020
O2	Thams Klyngen, Næringshagen i Orkdalsregionen	Orkanger, no	21-2-2020
O3	Kongsberg Teknologipark	Kongsberg, no	25-2-2020
O4	Skogmo Industripark	Overhalla, no	26-2-2020
O5	Proneo (Verdal Industripark)	Verdal, no	2-3-2020
O6	Industrial Green Tech	Herøya, no	3-3-2020
O7	Manufacturing Technology Norwegian Catapult (NCE Raufoss)	Raufoss, no	5-3-2020
O8	NCCE	Friedrikstad, no	12-3-2020
O9	Arctic Cluster Team	Mo I Rana, no	17-3-2020
O10	Solaris Parkmanagement / Parksharing	Nieuwkuijk, nl	8-4-2020
Platform provider (P)			
P1	Floow2 / Parksharing	Oisterwijk, nl	10-12-2019
P2	Stichting InduSym	Beek en Donk, nl	24-4-2020

Table 4. Organisation types and interviewees' positions.

Reference code	Position
Park management organization	
O1	Vice-president, head of marketing and business development
O3	Operating manager
O10	Junior parkmanager
Cluster organization	
$O2_1$	Cluster manager
O6	Cluster manager
O7	Chief executive officer
O8	Chief executive officer
O9	Cluster manager
Innovation and development organization	
$O2_2$	Business advisor
$O4_1$ and $O4_2$	Project leaders
O5	Head of advisory department
Platform provider	
P1	Co-founder, head of marketing and communication
P2	Creator, sustainability consultant

3.4. Data analysis

The digital recordings were transcribed at verbatim to be able to analyse the data. At first, the questions in the interview guide were used to divide the data into predefined parts. Then, as the interview was semi-structured and contained many follow-up questions, the data were coded using NVivo Qualitative Data Analysis Software, to give a first impression of the different themes. It was attempted to analyse inductively, but this led to themes that were too diffuse to present understandably, whereby it was decided to stick to a list of themes derived from earlier studied literature on IS.

3.5. Data validity

To secure the validity of the data, the interviews were conducted with persons that hold leading positions in firms and who are responsible for businesses development and collaboration related to IS. O10 (Table 4) holds the position of 'junior' manager but has been involved in the project in question from the beginning.

Since this is an explorative study into the rather new phenomenon of IS platforms, it is acknowledged that data validity is hard to secure. Even though the interviewees hold positions relevant to the topic and the concept of IS platforms was explained extensively, there may be some distortions of the interview data. Still, validity is enhanced by the use of semi-structured interviews with limited steering of the conversation and including open questions, without using difficult jargon.

4. Results from Norway

4.1. Barriers to Industrial Symbiosis in Norwegian industrial parks

In this part, the results will be discussed that answer the first sub-question: *What are the barriers experienced at supporting Industrial Symbiosis in Norwegian industrial parks?* Interviews with 9 organisations (O1-O9) operating at Norwegian industrial parks or clusters are analysed and the following will summarize the identified barriers. The data is divided into three overarching topics: the informational barriers, the economic barriers and the behavioural barriers.

4.1.1. Informational barriers

Most of the barriers to IS that were mentioned during the interviews are related to a lack of information on the market for secondary resources. Two different kinds of information failure are distinguished from the answers: a lack of information disclosure and a lack of competence.

4.1.1.1. Lack of information disclosure

One of the most cited barriers to IS holds that firms lack sufficient information about the resources that are present in the industrial park, which hinders the identification of potential matches. Interviewees point out that there is insufficient transparency about what the neighbouring industrial firms are producing, what inputs and outputs they have, and what kind of assets they own. O6 explained what firms complain about regarding IS:

> "… what they are saying today is that, 'I don't know who has something that I can use. I don't know where it is. I don't know if it's enough, the volume, and if the volume of one is not enough, how could we actually get the volume, collect more volume from others'." (O6)

Without knowing what other firms could use or supply, the potential of exchanging resources with them cannot be considered. Two respondents (O1; O9) indicated that some symbiotic relations are easy to identify, without the need for much exploration of the available resources in the industrial park. However, after the application of these "low hanging fruits" (O1) there is a lack of transparency to identify the more difficult matches.

Need for 'resource mapping'

A way to address the lack of information disclosure that was mentioned several times is to actively collect information about all the available resources in the industrial park, by 'resource mapping'. An overview is then made from the resource flows (inputs, outputs) from all firms, which enables the identification of potential for IS. Many interviewees (O1; O2; O4; O5; O6; O8; O9) pointed out that there is a need to perform resource mapping in order to support IS.

> "I think the barrier is the resource mapping" […] "… if you are going to identify the potential [for IS] you need to know what the facts are, and we have not done any resource mapping here." (O5)

The fact that this resource mapping is perceived as a prerequisite means that a lack of information disclosure currently obstructs IS.

Closed environments

O3 argues that the companies in his industrial park are operating in such closed and secured

environments, that they do not allow resource exchanges between them. The firms are specialized in researching and developing new technologies and wish not to be open about their resource streams to protect their knowledge. This hinders the identification of potential resource exchanges between firms and makes this kind of firms less suitable for IS.

Ignorant mind-set
$O2_1$ explained that the member firms from his cluster were not used to be informed about the activities of neighbouring firms before his cluster recently started to actively connect the firms.

> "And you live only 200 metres away from it [neighbouring firms], but you don't know what they are doing. So, I think that is the typical mind-set." ($O2_1$)

If firms are not used to be familiar with the activities of neighbouring firms, the chance of identifying any opportunities for IS will be low. This means that also a certain culture underlies the informational barrier to IS, which will be discussed later in section 4.1.3.2.

4.1.1.2. Lack of competence

Even if the availability of resources in an industrial park is transparent, there still may be a barrier to match the demand and supply of secondary resources. In order to successfully facilitate the matching, there needs to be sufficient competence to be able to implement these matches. However, this is not prioritized by firms.

Focus on core business
A couple of the interviewees (O7; O6; O9) stated that IS is not practised because it is simply not a part of their own business.

> "… they are totally occupied with their own business, with their own customers, with their own demands." (O7)

Firms are specialized in their production activities to serve the market demand instead of optimizing resource usage by cross-collaborations with other industries. The competence that is required to identify opportunities for IS is not regarded to be in line with the core business of industrial firms. According to O6, innovation has been very 'fragmented' at the companies in her cluster:

> "They [firms] have innovated a lot, but each of them in their separate companies. So the tradition, the culture for sharing has not been here. And we're starting more or less from scratch in the industrial area." (O6)

Firms do innovate to become more sustainable, but then they usually focus on themselves, for example by increasing the resource efficiency or emissions of their activities. Because of this fragmentation, these firms have not developed any competence to realize collaborations with other firms.

Third-party for competence
Sharing assets and exchanging by-products requires specific competence in which firms are not specialized.

> "… you have to have like an engine, to facilitate the sharing projects." (O7)

O7 implied that the 'engine' is not to be expected from the companies themselves. To facilitate IS, a couple of interviewees (O7; O9) suggests that a third party is needed. When it comes to sharing underutilized assets, O9 added:

> "… I think it [facilitating asset sharing] works best if you have companies that build their strategies on sharing assets. For a company, the main focus will always be the inhouse production. They will always prioritize using their assets to support the core business. This makes it harder to gain availability and access to the equipment for other companies, and in turn, it makes it difficult to make the symbiosis work efficiently. You want to keep the access steady enough to supply the market." (O9)

This points out that making resources available for potential IS is a strategy that is not in the direct interest of industrial firms, so another company specialized in this strategy should be involved. However, O6 was concerned about the difficulty to establish enough knowledge to facilitate IS in an industrial park. In order to exploit all potential of IS, there needs to be a source of knowledge about many different forms of resource exchanges and this would require the involvement of a substantial number of different experts.

4.1.2. Economic barriers

Many cited constraints to IS have economic reasons. As firms have the objective to generate profit, the decision to engage in IS will be driven by economic reasoning. On the question 'what is the most important barrier to IS in your industrial park?', O1 responded:

> "Well today, it's basically the financial models" […] "So choosing a very sustainable production system, which demands investments, if you can't get the customer to honour that investment, you're not able to do it." (O1)

Although IS has the potential to yield profitable exchanges for industrial firms, interviewees argued that for many exchanges the business case is too small on unattractive terms. Different economic barriers will be discussed further.

4.1.2.1. Risk aversion

Firms are reluctant to engage in IS projects because there is often too much risk to become less profitable. $O2_1$ explained that IS involves "too much investment on uncertain terms." Due to the lack of transparency, an initial investment needs to be done to assess the opportunities of IS. The fact that the economic potential of IS is unknown makes it risky for firms to make these initial investments. In addition, after the identification of potential symbiotic exchanges, firms often have to do large investments to enable the actual operationalization of the resource exchanges, for example in logistics or changes to the production system. These extra expenses make that the returns of the exchanges are not to be expected in the short term. Besides, often new technologies have to be used to enable some symbiotic exchanges, which may not have been proven in the industry.

> "It's being willing to take risk, and to step out of their comfort zone I'd say. They want to find solutions, and they know they have to find solutions for their waste and their emissions and so on. Now they've started some new collaborative projects in these areas to work towards their goals, but eh yeah, they are still not very risk willing." (O9)

The risk of ending up with a less profitable production process by using by-products will discourage firms to consider IS. O6 pointed out that it is important to note that firms are not willing to risk instability of their existing industrial operations. For example, when an alternative resource supplier is considered, the supply must be as stable as before in order to ensure no economic loss.

> "… they say: 'if we are going to change our process, it needs to be constant over a longer period of time', because if they are doing an innovation, they need to know that it's a reliable source of material that they can use." (O6)

Because the main objective of firms is to maximize their profit, they will be hesitant to engage in projects that risk being less profitable. When this risk could be reduced by feasibility studies, for example, firms can be motivated to consider IS projects.

Feasibility studies
Sound feasibility studies could support the firms' decision to invest in such projects. O1 explained that his park management organisation provides funding for feasibility studies to get around the unwillingness of firms to engage in IS projects due to unknown profitability. After the feasibility study, the firms can decide whether they continue with the project, which is then handed over to the firms.

> "… we are focussing a lot on feasibility studies that we finance ourselves, because an industry is very focussed on how to operate today and tomorrow." […] "They cannot use too many resources on ideas or things that they will not see any results from within one or two years. So, we need a good project description and we need to have some sort of pre-study and documentation of what is the actual benefit." (O1)

The provision of feasibility studies allows firms to assess the potential of IS projects that could otherwise not be assessed. However, in other industrial parks, firms cannot count on such support. Therefore, not all potential for IS could be assessed without financial support, which hinders the exploitation of IS projects that require further research than the low hanging fruits.

Resource mapping
The aforementioned resource mapping could be an additional way to identify IS opportunities, which could encourage firms to invest in considering exchanges. However, this resource mapping already requires substantial investments, making it reliant on external funding. According to O9, such a project is planned for the industrial park where O9 works in collaboration with Sintef (as an independent research organisation), but this requires governmental subsidy. The organisations applied for the funding, but they had to win the competition from other initiatives on a national level, in which they failed. The fact that governmental funding was a prerequisite for this project, underlines the economic barrier of identifying IS opportunities. According to O8 of the NCCE, the most important barriers to IS are a lack of investments by companies and the dependency on governmental funding. Therefore, she argued that the Norwegian government should play a more active role by financially supporting firms with IS projects. Without this support there is no business case and firms will not undertake the projects.

4.1.2.2. Internal distribution of resources

In addition, O6 remarked that large companies are less in need of optimizing resource usage because they have opportunities to redistribute resources over different activities within their firm. The economic benefit of exchanging with other firms is lower than when firms can keep the value of the resources within the company itself. Therefore, large firms rather consider retaining resources within the company than assessing the opportunities of IS, regardless of the potential gains.

4.1.2.3. Competition

Another possible obstacle for supporting IS in industrial parks is the competition between parent companies of the firms that are located in the same industrial park. O7 experienced this barrier in a project where they try to realize the shared usage of a production facility. The Norwegian managers

of the two firms were willing to participate in the project but since their foreign parent companies are competing in the same markets, they did not allow them to collaborate in the same project. The economic concerns of competitiveness could make cooperation between the two firms difficult.

4.1.3. Behavioural barriers

Some behavioural issues at firms underlie the informational and economic barriers. According to the interviewees, IS requires certain behaviour from firms that is not yet in place. The following paragraph will discuss the barriers mentioned by the interviewees, which are related to the unapt behaviour of firms.

4.1.3.1. Commitment to sustainability

Two respondents (O7; O9) mentioned that firms are not interested in IS projects because they are not committed enough to sustainability. Projects like IS are not initiated or actively considered because firms' managers do not view it as business opportunities, but as "only green" (O7). O7 remarked that sustainability is rather regarded as a side issue when investing in their own production facilities:

> "I'm not aware of every single project in the industrial park, but as far I know, the pure green projects are not very easy to recruit the industrial companies for, unfortunately. But if you are doing a development for their project or their business and in addition you get a better sustainability situation, then they are in. But if you come to present only green projects, not so interested unfortunately." (O7)

According to these interviewees, firms do not consider IS as a goal in itself, as it does not sufficiently benefit their own business, but primarily benefits society as a whole.

> "I think the main challenge, same as in other environmental innovation projects, is the society that's gaining. It's not one of the actors involved but it's the society that gains from us building these ecosystems [read: IS networks]." (O9)

This implies that the commitment to sustainability is insufficient to subordinate the economic interests to the environmental gains of IS. This is explained by the time-inconsistency problem that is relevant to many sustainable developments.

4.1.3.2. Prevailing culture

Several interviewees ($O2_1$; O4; O6; O7) pointed out that a large barrier for IS practices is the prevailing culture that is difficult to change. This barrier can be explained by economic reasoning and the commitment to sustainability; due to little constraints to reduce environmental impact and no limitations to resource availability, industrial firms have been focussing on short-term goals to maximize profits without the need for much collaboration. It takes time to change this, which is argued to be a barrier to IS.

> "I think the main thing is that they are not used to it [practising IS]. They have developed and done their business for so long without sharing with anyone else." (O6)

Therefore, it is not in the firms' culture to be informed about the activities of neighbouring firms, which relates to the barrier of a lack of transparency. O7 pointed out that for the current generation of firm managers, it is hard to change the organisational culture:

> "It's difficult to create a sense of urgency big enough, because that generation has experienced wealth, yeah it has been good times for them, so to say. …. That's a major problem for change management." (O7)

Unfamiliarity with asset sharing

Sharing assets can be considered as a new concept which industrial firms still have to get familiar with, as is illustrated by an example from one of the interviewees. $O4_1$ discussed a project they initiated at the industrial park, whereby they introduced the concept of asset sharing to the firms. The organisation bought a car that is available to book by the firms in the area. Through an easy system, it is possible to book the car whenever it is available. The booking fee is an "extremely low amount, […] the payment is only for covering the costs". More than a month before the interview they launched the project, which was received with enthusiasm by all firms, but the car was still not booked. The two interviewees agreed about the reason: the habit of sharing is "quite uncommon" ($O4_2$) in their industrial park and it is hard to change the way how people think.

> "There has to be, let's say, a mental change, an awareness of the possibilities." […] "the people are used to have this [their own] car available. Now they have to check if it's available in our booking system." ($O4_2$)

In addition, $O4_2$ argued that it is an old but still present habit that everyone should have his own car and even within households every person has one. This culture where ownership is very appreciated unfortunately also hinders sharing industrial assets.

> "… I think the same goes for companies as well. If I might need a tool, a crane, a car, one time, then you should own it yourself." ($O4_2$)

The adoption of new concepts such as sharing assets is regarded as difficult as a result of the prevailing culture. However, engaging in IS is considered to require other behaviour from firms, which depends on a cultural change.

4.1.3.3. Lack of trust and familiarity

The issue of mutual trust came up only once when discussing the barriers to IS in the Norwegian industrial parks. $O2_1$ emphasized its importance:

> "The biggest barrier maybe is trust. Lack of trust and lack of knowledge about the neighbour. They don't know what the neighbours do." "…. the biggest barrier of the trust issue is that they don't know each other and a they are a bit afraid of new things." ($O2_1$)

O2 highlighted that connecting neighbouring firms to get them sharing information about each other's activities is key in identifying IS. This suggests that the trust barrier is closely related to the informational barrier because trust is created by connecting firms with each other. When firm managers know each other and are familiar with each other's business, they will be more willing to share information and knowledge which solves the informational barrier to IS.

4.2. Interests in digital platforms to support IS in Norwegian industrial parks

After the interruption in the interviews, in which the ideas about the potential for an IS platform were discussed, the interviewees were asked what their main interests would be for using a digital platform to support IS. This paragraph will discuss 4 possible reasons why the Norwegian interviewees would be interested in digital platforms and why some of them are not interested.

4.2.1. Transparency

One of the most cited reasons for using a digital platform to support IS is creating transparency about the availability of secondary resources and assets in an industrial park. O2 and O6 pointed out that even the firms themselves ask for more transparency to be able to identify profitable exchanges. If participating in the platform is interesting enough, the firms could use the platform to publish data on their secondary resources that otherwise would be hidden. When more information on resources becomes available, the market for secondary resources becomes more transparent and more matches between supply and demand could be identified.

4.2.2. Infrastructure for IS

Another interest in a platform is that it could serve as an organisational structure to operate IS in an industrial park. By offering a common medium were all IS activity is centralized, O6 argued that it is much easier for firms to pick up the possibilities. The platform would align with the activities of her organisation.

> "I think it would be great to have it [an IS platform], in order to get the sharing going, in order to get the most of the resources that are in the area today. It would be a great tool, to actually reach the goals of the cluster." (O6)

In addition, $O2_1$ would like to use the IS platform as the main channel for firms to communicate about IS, not only for new matches but also for sharing experiences from existing collaborations. O1 commented on the potential for his industrial park:

> "We could call this an infrastructure tool, to create an even better market place for the industries, bringing up competence, bringing up competitive edge, being even more efficient. That could even be a service that we could provide, to our tenants." (O1)

This answer adds that it would be interesting if a platform could facilitate the distribution of competence since the IS activity is centralized in one virtual medium. It can be concluded that the interviewees would be interested to use a digital platform as infrastructure for communication and collaboration, to facilitate a more efficient marketplace for IS.

4.2.3. Medium for promotion

Being in the planning phase of a platform for their industrial area, $O2_1$ and $O2_2$ also recognized the importance of promotion to make firms join their platform. In their own project, they plan to on-board an initial group of firms that already are practising IS, to be able to show the profitable collaborations between these firms as an example for others. Next to "highlighting the success stories" through different channels like social media, the local newspaper and their new website, $O2_1$ planned to visualize the resource flows of existing IS collaborations in the industrial park. By promoting the success of exchanging and sharing resources by a small group of early adopters

through the platform, the interest in IS of other firms could be aroused. Thereby, $O2_1$ aimed to convince firms to use the platform to search for IS collaboration.

4.2.4. Attraction of business

By using their future platform, $O2_1$ and $O2_2$ aspired to create a network of IS collaboration in their industrial area. This network of firms could attract businesses from outside the area that is specialized in the CE and see opportunities in joining the network.

> "Maybe it can help us to get more start-ups from outside, because they see that there is here a network that is working so 'we want to join it, so we move to here'." ($O2_1$)

This means that the transparency that the platform creates could support the competitive advantage of an industrial park in comparison to other industrial parks. In addition, $O2_2$ mentioned that with this platform a change in mind-set could be created.

> "And even though they don't get anything out of sharing their resources at first, it is very important that they get this mind-set of 'this is a good thing, to contribute to the circular economy thought'." ($O2_2$)

The attention for IS in the industrial park that could be stimulated by the common platform acquaints firms with the actual practice and business opportunities of the circular economy. This could support a change in the thinking of industrial firms, which in turn could change the prevailing culture.

4.2.5. No interest

O3 questioned whether his industrial park needs a platform to support IS. He argues that the park is already functioning very well and there is no need for a digital platform to solve problems within this topic. O5 was not sure if firms would be interested in participating in this platform because now there is no direct need that could motivate the firms to share the information that is required to use the platform.

4.3. Critical factors for using digital platforms for supporting IS in Norwegian industrial parks

When the potential for an IS platform was discussed during the interviews, the Norwegian interviewees mentioned many different critical factors that are to be taken into account when using an IS platform. This section will discuss these factors one by one.

4.3.1. Time and resources at small-sized firms

Many interviewees (O1; $O2_1$; O4; O5; O6; O7) argued that participation in an IS platform would be more interesting and feasible for large firms than for small and medium-sized enterprises (SMEs). To make such a platform work, it demands from the firms to publish what they have in excess, by providing reliable and up-to-date data about their by-products and excess capacity. Most interviewees pointed out that the larger firms in their area would possess good internal systems that keep track of the occupancy of the production capacity and the streams of by-products. Some interviewees ($O2_1$; O4; O5; O6) argued that small firms do not have this data available and will have difficulties with finding time and resources to be able to publish the data. O6 said about this:

> "Thirty-four of them have 1-10 employees, 18 from 11 to 20 employees, you see the profile? So for these companies it has to be plug and play. It has to be really easy for them if they consider to be part of this system." (O6)

It points out that especially for the smaller companies in his area, it cannot take much effort to configure, because they have little time and resources to deal with a new platform. This makes the effect of firm size contradictory because in paragraph 4.1 O6 argued that large-sized firms more often have a good internal distribution of resources, making them less interested in IS.

According to $O2_2$ and O6, the small firms also have less to trade on the platform and would therefore not see the benefit of investing in the documentation of their resources and assets. On the other hand, O8 explained that she currently sees relatively more SMEs participating in IS projects, because their gains are relatively larger, and they will see profits earlier. However, these SMEs are often start-ups that have a business model build on an IS relationship, which makes the collection of data on their resources essential.

4.3.2. Willingness to share information

Next to the ability to share information on a platform, firms need to be willing to publish what resources and assets they have in excess. The unwillingness to share information is remarked in the literature as a large barrier to digital platforms in supporting IS. Therefore, specific questions were asked about factors that could influence the willingness to share information, divided in; mutual trust, the confidentiality of data and motivation to share.

Mutual trust
As IS involves the collaboration between different firms, their interaction requires a certain amount of trust. O9 pointed out the general importance of trust concerning the sharing of information:

> "…, building trust is the foundation for the cluster and in all our activities we need to have a basis of trust between the companies to get them to share information about their challenges or strategies or ambitions on different areas. And also, it's critical to get something like this [IS platform] to function, ..." (O9)

To make firms willing to disclose information to identify IS it is therefore required to have this basis of mutual trust. Also, $O2_1$ recognized the fundamental importance of trust among the firms to make them share information. Through their new cluster organisation, the neighbouring firms will get to know each other better, which is expected to improve the mutual trust that $O2_1$ saw as the most important barrier. For the same reason, O1 thought that the willingness to share information on a platform would be "quite mature".

> "… most of these companies are already organised into a cluster." […] "So, by introducing it [IS platform] into already existing systems, which purpose is to be more efficient, to be more transparent, and they are already sharing a lot of information between each other. So, through an existing cluster organisation, it would be the best way to introduce such ideas." (O1)

When firms in an industrial park are already organized in a cluster, O1 argued that platform initiators should use these to introduce themselves, since there already is a foundation of mutual trust on which an IS platform can build. Other interviewees have mixed answers about the issue of trust when the information sharing on a platform was discussed. Some interviewees (O7; O9) shared the opinion of O1 that there is sufficient trust among the firms in their industrial park, but they say that it depends on what data is to be shared, how open it is published, what actor is collecting the data and what benefit could motivate the firms to share data. The confidentiality of the data depends on what it can mean for competition. O9 had experience in a project in an oil and gas cluster, where they tried to share assets among firms:

> "… but they were so competitive, that they couldn't be open about these things [data on available assets]. We were trying to make the spreadsheets and platforms for sharing but they were not willing to be that open towards other competitors." (O9)

Data confidentiality

Most of the interviewees pointed out that a lot of information is confidential, but this strongly depends on what data has to be shared.

> "they won't share their inner secrets on any platform. But as long as you don't need that information, it [sharing information] would be possible." (O7)

O9 pointed out that firms might be protective about sharing data about production streams, which might be a problem for identifying matches. She argued that IS relationships as business partnerships require building a relationship of trust that cannot take place through an online platform.

> "… it's not that you can just come and shop a flow of materials or... it's more a long term relationship and it [IS relationship] needs to be prepared a lot for." (O9)

According to O1, it is quite possible for firms to share data on the availability of resources, but the pricing will not be shared openly on the platform. Financial data about the trades are too confidential and firms will not wish to share these.

> "By sharing what resources you have available, how many plumbers, how many welders, what certificate do you have, et cetera, I think that wouldn't be a problem. But when it comes to financial data I don't think so." (O1)

O5, O6 and O8 also recognized the issue of trust for a digital platform to work in an industrial park, but they argued that a neutral party is needed to convince the firms to use the platform. This neutral

party must have no intrinsic motivation to use the data for other goals than supporting IS, like a cluster organisation.

> "The data and the insights should be owned by, not a company, but owned by the representatives or the cluster project." (O5)

Motivation to share data

O1 argued that the motivation of the firms in his industrial park to become more sustainable would make them willing to share the information that is needed to identify IS among them. However, O3 and O5 thought that sharing such data for sustainability reasons would be problematic. O5 argued that there might be a lack of motivation to share data on an IS platform. O5 had experience with a project in Verdal Industripark, where they wanted to collect firm data about all the competence for the interest of his own organisation. From this project, he learned that you cannot just ask firms to provide data, but you need to create a direct benefit for them to provide it. In this case, the organisation decided to organise the competence mapping in collaboration with local schools and universities to be able to offer targeted courses and lectures to the firms in the park. In this way, they created a direct benefit for sharing the information with O5's organisation. It implies that clear communication about how providing information will fulfil the needs of the firms themselves is an important factor to make them willing to share data.

4.3.3. Ownership

Related to the factors of willingness to share information is the issue of ownership of the platform. As just mentioned when discussing the data confidentiality, the interviewees agreed that the platform owner needs to be a neutral party to convince the firms that the data is treated with integrity. The willingness to share information is enhanced when the data is collected by a neutral party because firms could fear the misuse of the information. Some interviewees (O5; O6) argued that this neutral owner should be a commonly owned organisation such as a cluster organisation.

> "… it should be a common owned company that owns the database. It could be the cluster or the business association. I would be sceptical if to run this database is a business. So the business model is critical." (O5)

However, O9 responded to the question of whether a cluster organisation should own the platform:

> "… you have to have resources and people running with a whole different competence than these companies. But they might be partly owners. Then again, if someone owns too much of this [IS platform] then it may affect the strategies in a negative way." (O9)

The lack of competence and underrepresentation in a cluster organisation are also factors to take into account. O9 further explained the importance of domain knowledge for building and running the platform to ensure "that the business model will work". With a successful business model, a platform can be operated independently from external funding, which assures the sustainability of the tool. This points out that to ensure the legitimacy to support IS collaboration among the firms in the industrial park, it matters who is going to own it. Both the integrity and the economic soundness are components that play a part in this issue.

4.3.4. Trustworthiness of information

In order to connect firms that seek and offer resources, an IS platform is reliant on the data that is published by its users. O5 pointed out that the platform would only work when the firms publish

trustworthy data about what they have to offer or supply. When firms publish incorrect information about the demand or supply of resources, the ability of the platform to provide valuable matches decreases. This is especially the case for descriptions of offered resources, as it is difficult for firms in demand to determine the quality of secondary resources.

4.3.5. Involvement of experts

Some interviewees ($O2_2$; O6) argued that the lack of competence could hinder the success of an IS platform in the industrial park where they are operating. $O2_2$ questioned whether sharing information about excess resources to address the lack of transparency would be enough to support IS matching:

> "And even if they put it [information about excess resources] out there [on a platform], do the companies have sufficient competence and knowledge how to use all the different material types. I doubt it to some extent. Maybe there should be someone who is actively with seeing how we can use these kinds of materials in different other areas." ($O2_2$)

This highlights the aforementioned barrier to IS, that the companies lack enough competence about IS to identify the matches themselves. The involvement of third-party experts to provide this competence is again suggested, in order to exploit the transparency that could be created by an IS platform.

4.3.6. Provision of incentives

Many interviewees (O1; O3; $O4_2$; O5; O9) expressed their concern that there would be a lack of incentives for the firms to start using an IS platform. O3, for example, thought that firms would be "quite sceptical, because they don't see the benefit of it." Initially, the firms will have no economic benefits of collecting and publishing information about their resources, because it is still uncertain whether a profitable match could be made. O1 commented:

> "… you will probably need to have external financing, because the companies here probably wouldn't have any direct benefits from being a part of such a platform." (O1)

The investments that are required to establish a platform to support IS are therefore not to be expected from the firms. Interviewees (O1; $O4_2$) noted the concern that firms will not presume that the platform would deliver actual results directly after the launch of the platform, which will discourage them to participate. In addition, $O4_2$ suggested that a future platform owner should be able to show the firms in advance what their financial benefit would be to make them join. A firm would only be convinced when he can see "in real-time" what the participation in a project will yield.

> "Then it is easier for them to see why they should use it [IS platform]. And that could be the selling point. And when they start using it, then they can really see the benefits from a platform like that." ($O4_2$)

Next to showing the economic potential, $O4_2$ argued that the platform should confront the firms with the environmental impact of their business as usual compared to engaging in IS. This could provide an additional incentive for firms that are committed to sustainability.

Since the interviewees indicated that the industrial firms will not have sufficient direct incentives to participate in an IS platform, the initial investments that are required for establishing the platform will not be made by the firms. To make firms to subsequently adopt the platform, the initiator needs

to find a way to communicate and even demonstrate clearly what the intrinsic motivation for firms is to participate.

4.3.7. Reluctance to change

An IS platform is a new online tool that is aimed to become an important part of the daily operations of industrial firms as an addition to managing systems that are already in place. Two interviewees ($O4_1$; O7) indicated that specific attention needs to be paid to the users' motivation that is required to adopt an additional tool. O7 explained that many new systems like IS platforms are invented by engineers that often underestimate the users' perspective. A new system might be developed to work very well in theory, but the actual functioning depends on the intrinsic motivations of the user to participate. $O4_2$ explained that the introduction of a new system is an extra hurdle, and has experienced this barrier with another project in his industrial park, where they provided the firms with a new software system. $O4_2$ explained that this did not work, because:

> "… they [firms] don't want to change the way they're doing things." […] "They would like to have something in the background, which they don't have to think about." ($O4_2$)

The firms want to have a solution that is compatible with the systems where they are working with already. Several interviewees (O1; O5; O6) argued that the platform needs to be easy to use and accessible for all firms in order to ensure its successful adoption. Otherwise, firms would not be convinced to use the platform if it could not blend in daily activities.

In addition, new digital tools require some experience and familiarity with devices and systems. O7 argued that the current generation of firm managers may not be familiar enough with digital technologies: "None of them are digital natives". She argued that this barrier to the use of digital platforms will fade by time, as more and more management positions at industrial firms are occupied by digitally competent personnel.

From these answers, it can be concluded that a lack of compatibility and competence of using new systems causes a reluctance to adopt a digital platform for supporting IS.

4.4. Summary of the empirical results from Norway

This paragraph summarizes the findings from the interviews conducted in Norway. The most important lessons from this data will later be complemented with the experiences with existing platforms in the Netherlands to substantiate chapter 6. To give a clear overview of the empirical data from the previous three paragraphs, the results are divided into three main themes, as is shown in Figure 4.

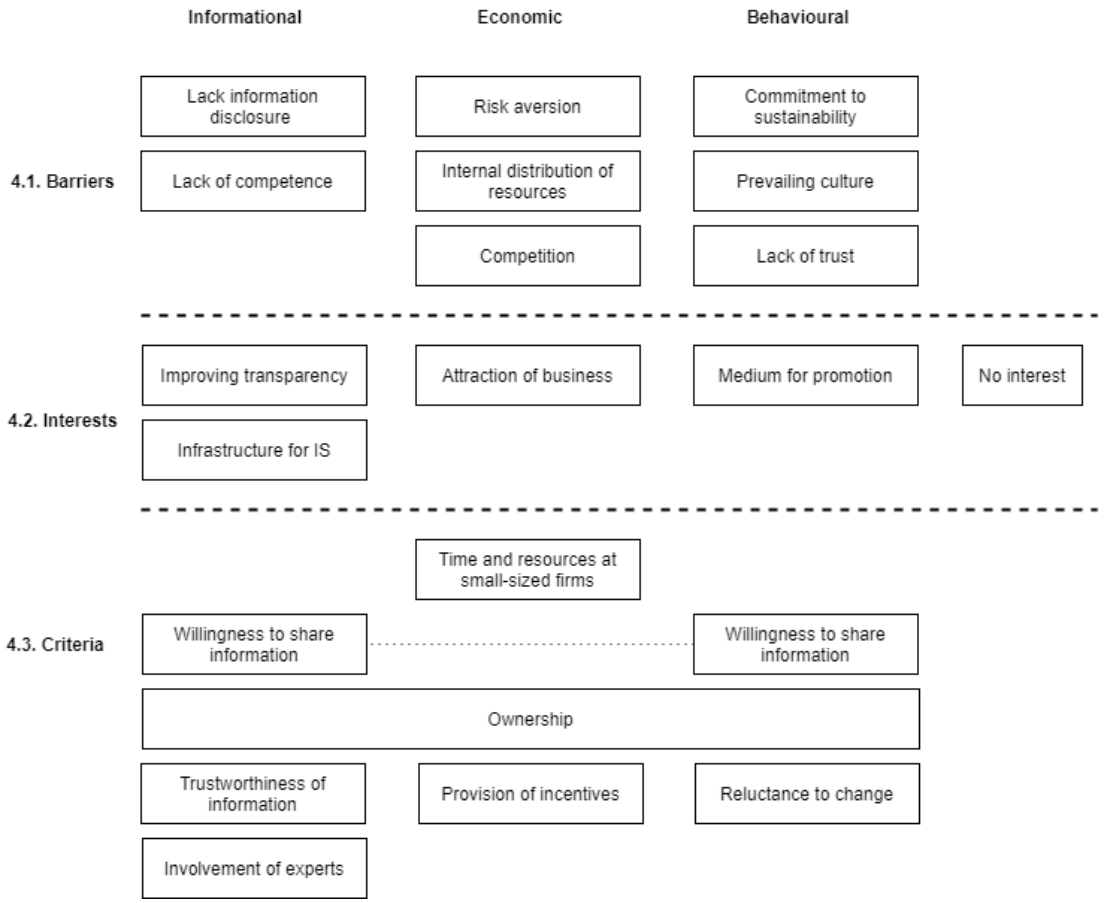

Figure 4. Summarizing scheme of paragraphs 4.1, 4.2 and 4.3.

The most cited barriers to IS concerned the information costs on the market for IS in Norwegian industrial parks. Due to a lack of disclosure of information about the availability of by-products and sharing assets, the search costs are too high to identify the potential of profitable exchanges. In addition, it appears that the interviewees expect that a transparent market is not sufficient to support IS, because firms then still lack the competence that is required to identify and implement the exchanges. The behaviour of firms (trust, ignorant mind-set) and economic reasoning (lack of incentives, focus on main activities) hinders the firms to share information, which is required to identify IS matches. The Norwegian interviewees would be interested in an IS platform, because it could provide a common infrastructure for IS, where all communication and knowledge can be centralized and distributed more efficiently. The digital platform could reduce the search costs by incentivizing firms to publish formerly hidden data on excess resources by providing an efficient digital market place. To provide the required competence to match and implement IS, the interviewees argued that third-party experts must be involved. Besides, the data published on the IS platform should be trustworthy and must be handled with integrity by a neutral party.

Firms are reluctant to engage in IS because of insufficient economic incentives. Due to high risks and low profitability of IS, the interviewees argued that firms are not willing to make the investments that are required to enable IS. Furthermore, the competition between firms could obstruct the collaboration to practice IS. A digital platform for IS would be interesting to alleviate the economic barriers by lowering the search costs for profitable exchanges. In addition, a platform is ought to support the formation of an IS network that could result in a competitive advantage to businesses with interests in the CE. However, the interviewees argued that the platform will not directly benefit the firms, so initial investments are not to be expected from them. When a platform would be in place, it should show in real-time what the economic incentives are to the firms, especially in the case for SMEs, since they have less time and resources available to make the additional effort that is required to implement a new system. However, the effect of firm size appears to be a paradox, as larger firms already have a good internal system to distribute materials more profitably. Moreover, to justify its economic sustainability, the platform provider needs to show a sound business model.

Other barriers underlie the informational and economic barriers to IS and are related to the behaviour of the firms' management. The business culture that prevails for a long time hinders the change in behaviour that is required to enable IS. Also, firms are often considered to have insufficient commitment to sustainability to engage in IS, which results in risk aversion and little incentives to invest in IS projects. Moreover, interviewees indicated that firms are reluctant to use new systems, as they might be unfamiliar with digital technology or just see it as a bothering effort additional to their daily activities. In addition, a lack of trust results from the fact that firms inadequately connect with each other, making it difficult to share information that in turn leads to a lack of transparency. However, there is interest to use platforms to enthuse firms in industrial parks to start getting involved in IS.

5. Results from the Netherlands

Now that the barriers experienced at supporting IS and the interests and critical factors for using digital platforms for this purpose are identified in Norway, this paragraph will investigate what can be learned from the experiences with two IS platforms running in the Netherlands. The experiences are derived from three interviews; two with representatives of two different IS platforms and one with a park management organisation that is affiliated with one of those platforms (Parksharing). Table 5 describes the characteristics of the two platforms.

Table 5. Characteristics of interviewed IS platforms from the Netherlands.

Name	**Parksharing – P1**	**InduSym – P2**
Year of establishment	2018	2017
Type of IS platform	"Facilitated synergy identification systems" (Table 2, section 2.2)	"Facilitated synergy identification systems" (Table 2, section 2.2)
Main (initial) focus	Asset sharing	Material exchange
Platform provider	Platform developer	Foundation (a collaboration between consultancy, park management and IT-provider)
Involved actors	Platform developer, park management organisation, collaboration platform, and government	Foundation, consultants, park management organisation, and government
Governmental support	Yes	Yes
Way of offering	Customized platform for each industrial park, including the option to search outside the park	One large platform database, open to any firm
Fee	Monthly access fee after a free trial period	Free access (ensuing consultancy services)
Number of participants	≈1500 firms	≈250 firms
Way of attracting users and gathering data	Free online "sharing scan" (questionnaire to calculate profitability) and personal approach through park management organisation	Paid "material scan" (on-site assessment of IS potential)

The experiences from these three interviewees will provide design criteria to using digital platforms for supporting IS. The data from the three interviews are divided into the platform criteria, the operational criteria and the external criteria.

5.1. Platform criteria

5.1.1. Compatibility with existing firm activities

Just as some Norwegian interviewees (O1; O5; O6), P1 argued that it should be easy to start using the platform so that it can blend in the daily activities and deliver the value that it proposes. She told that firms often think they need to radically adapt their production process in order to become circular, by for example redesigning their products. An IS platform should enable firms to proceed with the activities as they are used to, but should also engage them with IS by offering an easy-to-use service to find a valuable match. P1 explained that the platform that she offers is providing firms with the opportunity to easily become more circular and sustainable.

5.1.2. Data security

According to P2, the only real requirement that the users set to the platform is that the data needs to be treated securely and with integrity. Although, through his platform, there is not much data shared about the firms, because the accounts are initially set to publish demand and supply anonymously, and firms can optionally add firm information. In addition, the firms will do the communication and transaction between themselves after they have been matched via the platform, so no financial data could be collected by the platform. Still, the firms require that the platform of P2 guarantees them their privacy when it comes to account information and data storage, but this is already covered by the General Data Protection Regulation from the EU. Also, in the platform that P1 provides, the users can decide themselves what information they publish online. Despite the fact that the two platforms offer the option to stay anonymous, both P2 and O10 argued that it is beneficial for matching when firms reveal their personal details when publishing their demand and supply on the platform because then both parties already know with what kind of organisation they will come into contact.

5.1.3. Involvement of competence

Another criterion for an IS platform is the presence of competence to realize IS. O10 pointed out that there is a difference in complexity between realizing asset exchange and secondary resource exchanges. Asset sharing is relatively easy, since hiring out assets is quite straightforward, and the right usage can be learned with instructions. The realization of material exchanges, however, is more complex and requires more competence compared to asset sharing. According to P2, some matches are easily identified, the ‘low hanging fruits’, but many matches are more complex and require technical knowledge or innovative and unexplored technologies to realize.

As is discussed with the barriers to IS in section 4.1, firms lack the competence and experience in IS to realize complex matches. However, when the required competence can be provided by the involvement of experts in this area, these matches could become interesting. P1 provides this competence by the partnership with Symbiosis4Growth, a collaboration platform who helps firms to realize the business case of exchanges that would otherwise be too complex to make between the firms themselves. P2 has connected freelance consultancy services to the platform, so when questions arise from the matches that are made through the platform, the services to realize the matches are offered.

Interesting to remark is that P2 indicated that there is less specific competence required to offer materials on the platform (supply side) than to be able to use the offered materials (demand side). It

is easier to identify what materials can be exchanged since it is often waste what would otherwise be disposed of. However, to identify how these resources can be used as an input requires specialist knowledge. P2 explained:

> "What we see in the platform is that there is more supply of by-products that there are takers of by-products. So, for a firm to really dare to say 'I know how to use this product to produce something' surely requires technical or substantive knowledge about the material." (P2)

This means that the demand-side of the platform is underrepresented due to a lack of competence, thereby limiting the indirect positive network externalities for the supply side. The imbalance impedes the ability of the platform to provide the supply side with valuable matches with the demand side.

5.2. Operational criteria

5.2.1. Reaching critical mass

Before a critical mass of users is reached, the platform is not able to deliver the value that is intended to propose. This makes it very difficult for platform providers to give potential users the possibility to try out the service. O10 illustrated this for the platform at the parks that she manages.

> "They [participating firms] have to publish something, then they have to be matched, but that match is still not right every time, because sometimes the demand does not connect well with the supply. And when the first experiences are not entirely satisfactory, the people often think 'well, never mind, I'll just ask my neighbours if they can help outside the platform'." (O10)

This answer confirms the concern of the Norwegian interviewees (O1; $O4_2$) that firms do not presume the platform to be able to deliver direct results. Therefore, the first experience is important to be satisfactory to convince the firms that the value of the platform is worth the effort to participate. However, due to the chicken-and-egg problem, the platform of O10 had trouble to attracts either suppliers and buyers to reach a critical mass.

P1 dealt with this problem in two ways. Firstly, they use their partnership with a park management organisation to involve many member firms at the same time. By the existing communication channels and the automatic affiliation to the platform through the park membership, P1 told that it is easier to reach firms and create a critical mass of users. Still, however, the on-boarding of firms went "super slow", which made them see the need to partner up with another organisation, Symbiosis4Growth, to encourage firms more strongly to engage in IS. Together with this organisation, the platform organizes meetings, or 'work sessions', with firm representatives to actively identify opportunities for IS. The goal of these sessions is to use the knowledge from the firm representatives about their resources and the competence of Symbiosis4Growth to identify as many matches as possible. The resources that are not matched during the session are published on the platform, thereby increasing the amount of content and coming closer to the critical mass.

5.2.2. Inducement of platform users

The provision of work sessions is one way to support firms to become affiliated with the IS platform. To reach a critical mass of users, the platform needs to provide such inducements, which can be done in several other ways. A strategy that both the platforms of P1 and P2 are using is collecting the offerings and requests for resources and assets by themselves. In this way, the platform providers unburden the firms from the effort of publishing the demand and supply on the platform, that they ideally would put in by themselves.

P1 does this through the partnership with the park management organisation of O10, that visits the firms one by one to inform them about the park management services, including the IS platform. The firms are asked if they have excess resources to supply that can subsequently be published on the platform. Besides, the platform provides an online 'scan', which is a free-of-cost questionnaire that can be filled out relatively quickly by the firms themselves to calculate in advance what the potential profits of exchanging underutilized resources are. At the end of the questionnaire, the firms are asked to publish their excess resources on the platform.

P2 takes a slightly different approach by selling interested firms a service, whereby a specialized IS consultant assesses the opportunities of IS for the firm concerned. The firms are not yet committed enough to IS to take the effort for making an inventory and publish on the platform themselves. P2 explained:

> "So, we got around that [change in mentality] a little, because we provide that scan, we fill them out for them." […] "So, we drop by ourselves and make the inventory of the data ourselves." (P2)

The firms are provided with valuable matches from the direct network of the consultant and the unmatched resources are published on the platform, to be matched with later participants in the future.

Next to filling up the platform themselves, the platforms induce the firms by subsidization. The service to use the platform is offered by P1 for free for one year, although it is emphasized that this is used to reach a point where the platform provides sufficient value to stop this subsidization.

> "We have always said from the beginning that we are willing to facilitate towards the entrepreneurs for free, but not forever. So, at some point, there has to be a financial incentive for those firms to use it." (P1)

The usage of P2's platform is even completely free of charge since his revenue model is not dependent on the membership or usage of the platform.

5.2.3. Platform promotion

It is not among the standard business activities of industrial firms to be engagement in IS or to use a platform to offer or request resources and assets. P2 commented about this:

> "The main barrier is in fact to reach the entrepreneurs and to get them enthusiastic." (P2)

In order to get firms adopting this innovation, it is important to know the right ways to bring an IS platform under attention. P2 explained that "you need to have the right channels" to reach the people that are potential customers. For this reason, P1 collaborates with O10 to be able to promote

her platform in the industrial parks that are managed by O10's organisation. First, they introduced the project at general meetings, then they started a marketing campaign via social and local news media. Also, through the periodical newsletter of O10's organisation, firms have been instructed in the beginning how to use the platform and later reminded to actually start using it. P1 pointed to the importance of the collaboration between P1's and O10's organisations, as the park management organisation already has the connection with the entrepreneurs and is, therefore, able to use existing channels to promote the platform. As P1 explained, the difficulty of promoting is that many firms have to be approached to reach momentum, or critical mass. By using the collaboration with an organisation like O10's that unites many firms, you have "one front door" that enables you to approach more firms easier. However, P1 and O10 both remarked that it is still difficult to bring the platform under the attention of firm managers and it is important to repeat the communication to constantly remind the firms to use it.

In part 2 of the results, the plans of $O2_1$ and $O2_2$ were described to use the success stories of existing IS collaborations in the industrial park to showcase the potential of IS to convince others to join their future platform. This approach is also taken by the platform of P1 in collaboration with O10. She explained that in each industrial park they asked several firms that are operating in varying sectors if they have items they could share, to use as examples for the platform. The firms that were willing to participate are called "ambassadors" of their industrial park and their success stories were featured in videos that were shared across the industrial park. By showcasing the value proposition of the platform by promoting the examples of these "ambassadors" or early adopters, the interest of other firms can be aroused and can convince them to participate as well.

In conclusion, a platform initiator needs to find ways to promote the value proposition of the IS platform, since firms are not yet familiar with the use of the platform. The promotion could convince the firms to change their behaviour which is required to make them adopt the platform.

5.2.4. Platform governance

Another criterium that is identified from the interviews is the control of the behaviour of platform users. O10 explained that one of the firms in the industrial park had used the platform to sell its end-products instead of by-products. This is not in line with the value proposition of the platform, as it wants to stay exclusive for firms that search for opportunities for IS to keep its credibility and value for supporting IS. The platform prevents this adverse behaviour by warning or banning users that exhibit adverse behaviour.

Similarly, the aforementioned barrier of trustworthiness of information also indicates that platform users need to behave to certain requirements to maintain the value of the platform. Namely, when platform users publish incorrect information about their request or offer, the platform's ability to make the right match decreases.

Adverse behaviour of users can threaten the ability of the platform to deliver the value that it proposes. The platform should, therefore, enforce the right behaviour by setting usage rules and subsequently punish users when they violate them.

5.3. External criteria

5.3.1. Change in mentality

The adoption of an IS platform requires firms to be committed to sustainability and to be willing to change their business, which is pointed out by P1:

> "They actually never have to think about other things than executing their daily production processes. Therefore, they really have to do it [participating in an IS platform], because they want to do good for the environment and many firms just don't have that." (P1)

Firms still prefer to buy new resources and assets from the suppliers they already know, because it is easy, fast and reliable. As concluded from previous parts, firms perceive IS as more time consuming and requiring more effort and insecurity than the conventional way of production and procurement.

> "What we noticed with entrepreneurs, is that they are really occupied with doing business. They really want to help their neighbours, but they often say already 'oh, my secretary will do that, or someone else', because since they are so busy with their daily activities, such things are quickly forgotten. Besides, it is still a purchasing economy; it has become too easy to just buy new things." (O10)

To realize the active participation to IS platforms, so when the publishing of supply and demand happens on the firms' own initiative, a change in mentality is required; a mentality that converts the environmental awareness into sustainable business practices. In section 4.3, $O4_2$ suggested that platform initiators should confront firms with the environmental consequences of their current business activities to provide them with an incentive to engage in IS. Showing the environmental gains of IS could influence the firms that are committed to sustainability. This was one of the reasons for P1 to develop the online scan that firms can use to calculate what participation to the platform could yield in economic and environmental terms. By providing this easy and accessible tool the change in mentality can be encouraged, which increases the chance that firms will use the platform.

According to P2, the required change in mentality is not expected in the near future, but the societal transition is already set into motion. Also, P1 pointed out that it is going to require perseverance from her organisation and states:

> "We just know that there are many excess by-products and underutilized assets; at any firm, that's just a fact. But a lot of entrepreneurs are not yet thinking about it [exchanging and sharing resources], because they're doing things the same way for 50 years and it's going just fine like this." (P1)

However, P2 argued that IS is one of the rare kinds of sustainable practices that yield economic returns that, whether or not in the long term, provide a business case as motivation. Moreover, the prices of secondary resources will eventually rise resulting in an even stronger incentive for firms to engage in IS, because exchanges through the platform will suddenly become profitable. Here, there is also an important role to play for the government by encouraging and incentivizing the choice for IS.

5.3.2. Clear and supportive governmental policies

The government has a large impact on the choices that industrial firms make by setting regulations and granting subsidies. The role of the government is therefore often pivotal for setting sustainable

practices in motion. One of the barriers to IS at Norwegian industrial parks that was mentioned by O8 is the dependency on external funding, which is insufficiently solved by the government. The two cases of P1 and P2 confirm the issue of financial dependency on the government, as both platforms are financed with subsidies. Some local governments that have the circular economy on their agenda, made funding available to financially support the organisations of P1 and P2, which enabled the establishment of their platforms. P1 emphasized that the platform is always intended to become independent of subsidies.

> "And in the end, it has to become a sustainable platform. So, what you often see, is a platform entering the market without a revenue model. Then, in fact, you do not have a future, because you cannot sustain from subsidies forever. That is impossible and that was also a requirement from the government, that the platform would eventually become self-sustaining." (P1)

This points out that the granting of government support does not permit the platform to have a revenue model that is dependent on this support. P1 added that the government could encourage them by removing regulations that constrain IS practices, though no further explanation on this was given.

To summarize this chapter, Figure 5 depict the different criteria divided in three groups.

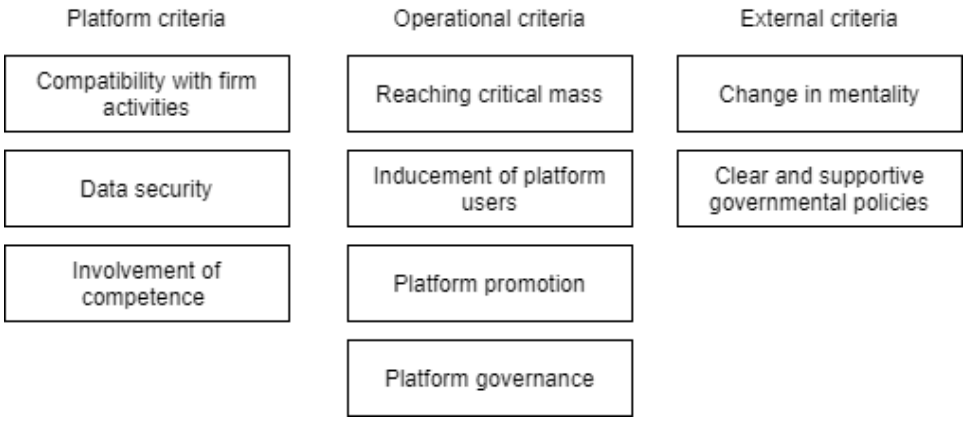

Figure 5. Summarizing scheme of chapter 5.

6. Conditions for a minimum viable platform for supporting IS in Norwegian industrial parks

The success of the digital platforms' business model has resulted in new economic theories, that were discussed in chapter 2.2. These theories explain how digital platforms help resolve transaction costs in homogeneous business-to-consumer markets. However, the application of the digital platform business model to resolve transaction costs for IS appears to be less obvious, as the previous chapters have pointed out. Until now, the results have provided the most important factors for using digital platforms for supporting IS, on the one hand by analysing the experiences and critical factors from Norwegian industrial parks in chapter four, and on the other hand, by identifying the design criteria from experiences with existing IS platforms in the Netherlands in chapter 5. From these results it is still not clear how a digital platform should be applied to support IS, since the data have to be interpreted to provide steps in the process of establishment. This chapter will, therefore, combine the interview data and the theory discussed in section 2, to construct a set of conditions for a *viable* approach to use digital platforms to support IS in Norwegian industrial parks.

Here, it is important to note what is meant by *viable*, as it can be conceived in different ways. In this thesis, the distinction is made between an IS platform that is operationally viable and one that is commercially viable. The former describes a platform that is working properly and to the benefit and satisfaction of its users, in the sense that industrial firms actually would be willing to use the platform, regardless of whether they have to pay for it or not. However, with this conception of *viable,* it is still possible that the platform is generating insufficient economic value to sustain itself. When it is reliant on external funding, the platform needs to be able to either ensure continuous support or to convert its dependence on external funding into a self-sustaining business model. The latter conception, about whether or not the platform can be commercially viable, is a secondary question, that will be answered at the end of this chapter.

The theory on platform economics (section 2.2) together with theories on the innovation ecosystems (section 2.3) will be applied to the case of supporting IS in Norwegian industrial parks. As explained in theory section 2.3, the success of the establishment of an IS platform can be improved by starting with a minimum set of features of the platform that is eventually aimed for. Therefore, the first 4 paragraphs of this chapter will identify the conditions to a minimum viable ecosystem for an IS platform, or a minimum viable platform (MVP) for IS, based on the interviews. By applying these conditions, the last paragraph will describe the MVP for a demonstrably and successful platform for supporting IS.

Not all criteria that are discussed in the previous chapters will be used to set out the conditions in this chapter. Several criteria are not characteristic for the establishment of a platform business or for supporting IS and will therefore not be elaborated on in detail, but will be shortly discussed in the following.

Firstly, the design for a user-friendly platform can be copied from similar platforms. Therefore, the design of an understandable user interface is not necessarily a major issue. Ensuring data security will neither be a large task to ensure since modern technologies are able to encrypt the data that is shared on the platform. Especially the application of blockchain technology could enable a safe exchange of data about secondary resources. For promoting the platform in order to on-board as many firms as possible, a sound marketing strategy has to be developed. This strategy must take into account that a large behavioural barrier must be overcome. However, many platforms have already succeeded in persuading customers with marketing, so IS platform initiators will be able to imitate

the strategies of those. The required change in mentality is possible to influence by promotion, but it will largely rely on the societal developments, which are so complicated and unattainable that it is left out of consideration in this thesis, to focus on the conditions that are specific to establish a platform in the context of IS.

The rest of the criteria are considered specific to an IS platform and will be discussed further in this chapter. By using the findings from the interviews that are described in the two previous chapters, the next 4 paragraphs will explain what conditions a platform initiator will have to meet to establish an MVP to support IS in Norwegian industrial parks. The last paragraph will describe the MVP that meets these conditions.

6.1. Co-innovation risk

In order to enable an IS platform to facilitate matchmaking on the market for secondary resources, it requires its users to be ready to supply and demand through the platform. However, for an IS platform to make matches it is reliant on the innovations that have to be implemented by its participants. This will be explained by using the concept of co-innovation, which is discussed in section 2.3, for both the supply and demand side of the market for excess resources. Thereafter, the degree of standardization will be used to describe the difference in co-innovation risk for certain transactions.

Supply-side innovations
Platforms have the ability to reduce the transaction costs by reducing the search and contracting costs, but on the condition that firms provide the information on their excess resources that are to be traded. The problem is that there is no sufficient information available on many excess resources since firms do not have the incentives (section 4.3) or lack the time and resources (chapter 5) to collect this. Firms first have to implement innovations to monitor the quantity, quality and location of the resources to be able to offer them on the platform. In this way, the platform's success is dependent on the co-innovation of firms that have excess resources to supply. One can think of technological innovations, such as for resource monitoring or even organisational innovation as in a change in administration. Especially, the co-innovation risk at SMEs is high, since they lack time, capital and good internal systems to manage their resources (section 4.3). If a platform provider is looking for an MVP it is important to reduce this risk, to successfully facilitate transactions. However, the extent to which innovations from the suppliers are required differs between the types of transactions, which will be explained after discussing the co-innovations required at the demand-side.

Demand-side innovations
Chapter 5 discussed an imbalance between the demand and supply-side on the market for secondary resources. Too little firms are willing or capable of using many secondary resources for different reasons, such as a lack of competence, risk aversion and weak commitment to sustainability (section 4.1). The imbalance should be resolved by innovations at the demand-side; firms need to innovate their production process before they are able to replace virgin resources by the secondary resources. The platform is limited to facilitate trade in those resources for which firms are ready to use them and is therefore dependent on the innovations on the demand side. In order to reduce the co-innovation risk at the demand-side, the IS platform provider should focus on transactions of those goods for which it is sure some firms are able to use them.

Degree of standardization
In chapter 5 was discussed that the exchange of by-products is more complex than the sharing of underutilized assets. Renting out assets is considered quite straightforward and the right usage can be learned to anyone with instructions. Material exchanges, however, are more complex since there are many more requirements for the quality and quantity of the traded goods. The difference in complexity between asset sharing and by-product exchange can be explained by the degree of standardization of goods, meaning that access to one specific asset offered by different firms is regarded as relatively identical, regardless of which firm supplies the access. For the exchange of by-products, there are many more requirements to the quality and quantity, making it necessary to collect more and specific information about the goods to find the right match, which in turn requires more co-innovation from the firms at the supply side. In addition, the quality, quantity and location of assets are easier to administrate and to assess their requirements for firms at the demand side. The relative simplicity of asset sharing compared to other forms of IS, eliminates the need for involvement of specific competence to be provided by a third party (section 4.3 and chapter 5). Since firms are able to fulfil the transactions by themselves, less organisational innovation is required to establish trade. Moreover, less standardized resources require more innovations to be able to substitute them for virgin resources in the production processes of firms, thereby causing a higher risk to be reliant on co-innovation at the demand side. Highly standardized resources, such as wooden pallets or access to a forklift, are easier to use in the existing firm activities. For these reasons, the trade in more standardized by-products and access to assets is less dependent on co-innovation and should, therefore, be started with at the MVP.

6.2. Critical Mass

From the platform theory, it is known that a platform can only deliver value to its participants when a critical mass of users is reached because then it provides the indirect network effects that are valuable for the users. Therefore, a platform with minimum viability must be able to reach a critical mass. The chance of creating a critical mass for IS can be increased by taking the following three issues into account.

Chicken-and-egg problem
Reducing the co-innovation risk is not sufficient to ignite the growth of participants at both platform sides. As discussed in section 2.2.1, platform providers have to solve the chicken-and-egg problem: an IS platform will not attract buyers without having any firms offering their resources and will not attract any suppliers without having any firms interested to buy resources. The platform provider should find a way to reach the critical mass frontier for both sides: affiliate enough suppliers to attain value that attracts buyers and vice versa. In establishing an MVP, the platform provider has to find the easiest way to solve the chicken-and-egg problem. This can, for example, be done by offering a service or product for free; the platform subsidizes users of one or both platform sides, to attract a critical mass (as explained in section 2.2.1.4.). However, it is dangerous to attract platform users with subsidization, as it increases the risk to attract users that will leave once the subsidization stops. The subsidization should, therefore, continue after reaching the critical mass frontier or the platform must increase in value to the extent that convinces the subsidized users to stay.

Problem of heterogeneity of the market for IS
The famous two-sided platforms, like Airbnb and Uber, are very successful in resolving the transaction costs of relatively homogeneous sets of goods or services, meaning that there are no large differences between the units that are traded through one platform (e.g. merely apartments or

ride services). In these cases, a participant joining one side of the platform immediately increases the value of the participants on the other side of the platform, since it increases the chance to find a valuable match. The market on which IS platforms try to resolve the transaction costs, is by contrast very heterogeneous, as is discussed in section 2.2.2. It varies from exchanges of all different kinds of materials to energy, water and access to underutilized assets, so the platform does not provide network effects for one market for IS, but in fact for countless markets for countless secondary resources. The network effects that are supposed to attract firms to join do not increase automatically with one additional firm joins, because this one additional firm may seek or offer a different resource than what the current platform users are interested in. Therefore, the value of the indirect network externalities of an IS platform is much harder to assess when the market that is facilitated is heterogeneous.

When a platform provider limits its focus for the MVP to the exchange on goods for which he knows that there is a thick market (section 2. 2), he increases his chances on reaching a critical mass, as the platform user is more likely to be attracted by the indirect network effects that the MVP provides for the market where the user is interested in.

Recurring transactions
The indirect network effects that digital market places provide are valuable to platform users for each transaction. The platform's value for the user, therefore, increases with the frequency of using the platform. This frequency differs between asset sharing and by-product exchange. An asset is rented out for a period, to be rented out again to another firm when the period ends, thereby using the network effects from the IS platform repeatedly. When by-products are exchanged, it most often involves a long-term agreement to be able to ensure a reliant stream of inputs and outputs for both platform users. Therefore, the suppliers and buyers involved in the transactions of by-products will get together through the platform less often than for transactions of asset sharing. A thick market for asset sharing is, for this reason, easier to reach because more participants are attracted and thereby increasing the chances to reach a critical mass. In addition, since firms will be willing to access the platform more frequently for asset sharing, subsidization by granting free access is more valuable than for by-product exchange, thereby increasing the chance to successfully reach a critical mass. Similarly, recurring transactions increase the amount of feedback and ratings that firms could publish on each other, thereby solving trust-related issued by reducing the number of low-quality sellers.

6.3. Existing industrial networks

Oftentimes industrial firms are already organized in a network, such as the management organisation of the park where the firms are located or a cluster organisation, whether or not focussed on a specific industry or issue (e.g. CE). This paragraph will discuss three reasons why these network organisations are important for a platform.

Quick affiliation of firms
In chapter 5, the collaboration is explained between Dutch platforms and park management organisations. An existing network of industrial firms is leveraged by the platform to affiliate a large initial group of participants, which supports in reaching the critical mass of users. The communication channels that are already in place for the network can be used to promote the value proposition of the platform. As discussed in chapter 5, the persistent promotion of the platform is needed to inculcate the firms' behaviour to use the platform. Also, in chapter 4 is pointed out that the

successes through the platform could encourage a change in mind-set of other firms in the area that will further increase the number of platform participants.

Existing trust
As explained in section 4.3, many firms are already organized in clusters, where they collaborate in projects focussed on reducing environmental impact. The foundation of mutual trust between these cluster members enhances the information and knowledge sharing through an IS platform. The partnership with already existing industrial network organisations, therefore, provides an IS platform provider with an initial amount of trust that supports the ignition of the platform.

Geographical boundaries of platform
Besides the affiliation, communication and trust that already exist in industrial networks, member firms are also located close to each other. This reduces the transportation costs that are involved in the transaction to be facilitated through an IS platform. Especially for energy, water, large volumes, and low-value transactions, the geographical proximity will be crucial for facilitating trade. However, there is also a disadvantage of having a platform centred on one specific area since firms can only interact with other firms in the area that they already know. For by-products, which are less standardized, it is less likely to find a good match within the boundaries of an industrial park or cluster, as it often already considered IS with firms that it is familiar with. Therefore, the network is preferred to contain a larger pool of firms, stretched out over a larger geographical area. Still, the profitability of the transactions is constrained by transportation costs, although large quantities of specific valuable materials could be worth the travel distance. Asset sharing often involves small transactions or immobile assets (e.g. machines, office space) for which transportation costs are too high.

6.4. Legitimate ownership

In chapter 5, it was discussed that in order to showcase the value proposition of the platform, the right user behaviour should be enforced. To be able to exercise authority for governing the platform, the owner needs to have a degree of legitimacy. The legitimacy of the platform owner is explained with three different aspects.

Environmental legitimacy
When its full value proposition is reached, an IS platform is aimed to become the infrastructure for IS. By facilitating unprecedented matchmaking, the platform would be essential for the circular allocation of resources, thereby generating environmental value that accrues to society as a whole. Since the platform would bear the responsibility to serve the CE, the owner needs to have a certain degree of legitimacy. One could argue that the platform owner must be trusted to be intrinsically motivated to deliver the environmental value, otherwise, businesses could become suspicious. In this regard, the legitimate owner would preferably be the government, as it is elected to act to the benefit of the society. Therefore, the government can justify expenditures on subsidies for an IS platform from which the society benefits in terms of environmental gains, in contrast to private investors that need to justify this to shareholders that only benefit from profit.

Economic legitimacy
Differently, it will be in the businesses' interest that the platform sustains its function because in the full value proposition the firms would become reliant on its services to find valuable matches. In this regard, one could favour a business to run an IS platform more effectively, since it is driven by reducing costs and inefficiencies. In section 4.3 is explained that a company specialized in the

platform business should be the owner, to ensure an effective revenue model that is independent of external funding. Because a business is driven by making profits, one could say a firm has more legitimacy to ensure a self-sustaining business model than the government. Moreover, in section 4.1 it is argued that the platform owner should be a firm that is specialized in establishing platforms, instead of a firm that has other activities as its main focus, such as one of the manufacturing firms in the park.

Moral legitimacy
Next to bearing the responsibility of serving the CE, an IS platform owner needs to gain the trust of the firms to possess valuable data. The platform would only be functional for matchmaking on the condition that firms publish correct data about their excess resources on the platform. As the number of participants will grow, the platform will receive a larger load of information about all these transactions, which could be confidential data, as is pointed out in chapter 4.3.2 and chapter 5.1.2. To make sure that firms will entrust the platform with this information, a neutral party should operate the platform and own the database. In section 4.3.3 is remarked that firms would be sceptical if one single business would own the database, but a commonly owned organisation may be unfairly represented, resulting in unbalanced management that disadvantages the smaller firms. This again advocates a state-owned platform, given that no perverse motives prevail in case of an integer government.

6.5. Minimum Viable Platform for supporting IS in Norwegian industrial parks

This paragraph will discuss the MVP that applies the conditions that are set in the previous paragraphs. It is explained why the MVP should start with asset sharing, to be expanded to eventually involve by-product exchanges as well.

An MVP for asset sharing to reach critical mass
Firstly, to keep the risk of co-innovation low, the MVP should focus on asset sharing. Little innovation is required from the industrial firms, as information about an asset is easy to administrate and its requirements are easy to assess. In addition, no large changes to the production process are needed to use assets, as it simply replaces assets that were otherwise bought as new. Yet, the firms need to become familiar with the habit of asset sharing instead of owning them. Still, since the co-innovation risk for asset sharing for firms at both the supply and the demand is low, the chance to create a large number of participants wanting to get together through the IS platform is increased.

However, secondly, the platform has to solve the chicken-and-egg problem. To attract an initial group of participants, the platform should find a strategy to provide an incentive to persuade firms to join the platform. A common strategy is subsidization, by granting free access (whether or not limited to a trial period) to provide an attractive service to the firms (Demary & Rusche, 2018). This would work better for asset sharing since it involves recurring transactions. In the same way, the recurrence of transactions for asset sharing provides a thicker market than for longer-term transactions in by-product exchange, because for those transactions you would only visit the platform once in a long while. In addition, as the value for the participants increases with the indirect network effects and the indirect network effects increase more quickly for a homogeneous market, the platform should focus on a limited number of assets for which it is certain to create a thick market.

Thirdly, the MVP should be established in collaboration with an existing network organisation for industrial firms. Through the quick affiliation of firms, it is possible to efficiently promote and persuade a critical mass of participants. In addition, the existing foundation of trust also makes it easier to attract an initial group of firms to get together through the digital platform. Moreover, to keep transportation costs low, it works better if the firms in the network are in close proximity, such as for park management organisations or cluster organisations. Preferably, the initial network for an MVP would consist of a large number of firms to provide a larger pool for reaching a critical mass of platform users. Entailing more standardized products, asset sharing is more likely to be facilitated within the geographic boundaries of an industrial park since fewer specific requirements are needed to find a match.

Fourthly, to have the authority for governing the platform, the owner needs to have a certain legitimacy. It simultaneously needs to justify its motivation to reduce environmental impact, provide a sustainable business model to its users and to confidentially manage the published data. A government has more environmental and moral legitimacy than a business since it is elected by the people and has, therefore, the motivation to act in the interests of both the firms and society. However, the legitimacy to ensure a sustainable business model is predestined for a business owner, because it is driven to eliminate costs and inefficiencies. Hence, there exists a tension which cannot be solved without compromising on either economic legitimacy or environmental and moral legitimacy. However, since there is external funding needed to subsidize firms to participate and there are no incentives for private investors due to high initial costs and uncertain revenues, the government is required to take ownership, or at least to participate in a public-private partnership. Besides, the environmental gains from the platform are of concern to the government, which can legitimize the expenditures on the platform to its people. Nevertheless, the continuity for businesses cannot be guaranteed as the subsidy can be stopped abruptly, although the government has to make a long-term commitment to convince industrial firms to undertake participation in the platform.

Potentially, the government can connect compliance to certain regulations to the platform, thereby creating an extra incentive for firms to participate in the platform. For example, firms can be obliged to publish information on their excess resources that then automatically become available for the platform. This could stimulate transparency and therefore would encourage firms to innovate production processes to be able to substitute primary resources by secondary resources, which will increase the number of firms on the demand side.

Platform expansion to industry platform

The MVP consists of minimal conditions to the platform to be able to create a critical mass. After having successfully established an MVP, complementary elements can be added to step-by-step achieve the provision of the full value proposition that was aimed for: a digital platform supporting IS by enabling a digital market place and fostering co-creation. Adner's (2012) concept of staged expansion can be applied by allowing external organisations to co-create additional services for the platform. These additional services would complement the platform, such as payment services, legal support, software add-ons, et cetera, to increase the value creation potential of the MVP. The providers of the services use could exploit the platform's value that created by the network effects, to interact with the participating firms, thereby forming an ecosystem of firms that facilitate the full value proposition of IS as defined by Lombardi & Laybourn (2012) in 2.1.1.

Explained in the context of an innovation system, the initial 'physical market side' (consisting of sellers and buyers of secondary resources) of the platform could be gradually expanded with service providers on the 'complementary service side' of the IS platform, as is depicted in Figure 6. In this

way, the initial digital market place of the MVP could evolve in an industry platform as explained in section 2.4.

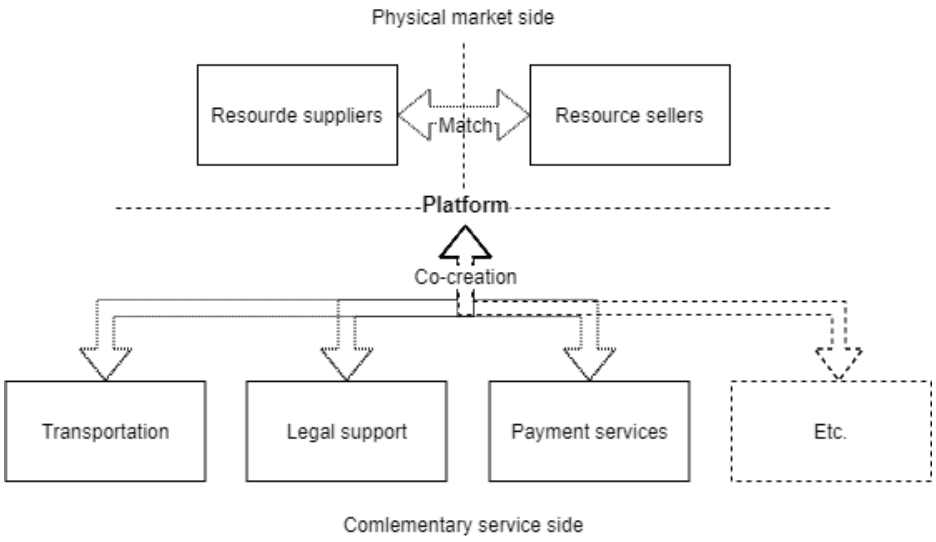

Figure 6. Double-sided IS platform, including providers of transportation, legal support and payment services as an example.

Platform carryover to involve by-product exchange

By providing transportation services, the trade between firms outside the initial network could be facilitated, to connect and expand the pool of participating firms. In this way, the exchange of by-products becomes more relevant, as less standardized resources require a larger pool of participants to find a match. Moreover, when other industrial networks develop similar platforms, with compatible databases and platform governance, the different platforms could eventually be connected, to create a larger network of firms. This potentially enables the platform to reach a critical mass for the market for by-products. However, from chapter 4 and 5 it appeared that the competence required for by-product exchange is not in line with the firms' competence to run their business. This corresponds with earlier literature, by Golev et al. (2015) described in section 2.1.2 and by Benedict et al. (2018) in section 2.2.2.2. Therefore, by-product exchange will not be successfully facilitated by solely the transparency that the IS platform provides, but requires the involvement of experts to assess the opportunities of matches. To provide the competence of experts, the services of CE consultants could be connected to complement the IS platform. The positive network externalities can be leveraged by the consultants by receiving more service requests and firms are attracted by the availability of competence provided by the connected consultants.

Important to note is that regarding by-product exchange, there is a larger issue of co-innovation risk than for asset sharing, as explained in section 6.1. In fact, there is a chicken-and-egg problem for co-innovation, since on the one hand firms will not innovate to provide information about resources for which there is no demand, and on the other hand firms will not innovate their production process when they don't know whether they can buy a certain secondary resource to substitute their current primary resource input. However, as P1 also stated in section 5.3.1, it is a fact that the excess by-products are there, and when this chicken-and-egg problem is solved, more supply and demand could eventually be matched, while simultaneously generate environmental value.

It can be stated that a large sacrifice is needed to overcome the dependence on co-innovation from the firms. With this sacrifice of up-front investments and risks, a critical mass of IS practitioners can be achieved that are ready to interact on the IS platform. However, as chapter 4 described, firms have insufficient incentives to invest in IS, since there are mostly environmental gains, and those

accrue to the people and not to the firms who invest. The government is paid by the people through taxes and acts in their interest. If IS platforms are expected to generate significant environmental value by enabling a CE, this should be a motivation for the Norwegian government to make the sacrifice. One can argue that the environmental gains resulting from industrial asset sharing alone will not be large enough to convince the government to make such a commitment. Support of IS that covers all types of secondary resources will have a much larger impact on the transition to a CE and may be the only outcome that is considered to be worth the investment. However, this research explained that before a digital platform is able to support the entire range of resource exchanges, it has to start with sharing assets alone, and needs the government to stick to the commitment for enabling the complete development of an IS platform.

The Norwegian government should take the role of an 'ecosystem leader', as explained in section 2.3.1.1. by Adner (2012), by making this sacrifice to create an ecosystem that enables the establishment of a full-fledged IS platform, allowing to eventually reap the rewards. Norway, owning world's largest sovereign wealth fund (Twin, 2019), may be the country specifically being fit to take this role, as its Ministry of Finance states that "a sound long-term management of the Fund contributes to intergenerational equity, by allowing both current and future generations to benefit from the petroleum revenues" (Ministry of Finance, 2007).

7. Discussion

7.1. Conclusion

This thesis addressed the question *'How can a digital platform support Industrial Symbiosis among local businesses?'* for the case of Norwegian industrial parks. Since there were no IS platforms found in Norway, empirical data from Norwegian organisations are complemented with experiences with two running platforms that support IS in the Netherlands. The important components of supporting IS with digital platforms are firstly determined in Norwegian industrial parks and subsequently, the design criteria are identified from the experiences with the Dutch platforms, to be able to construct the conditions for a minimum viable platform (MVP). By starting with this minimum set of features of the envisioned platform, the chance to successfully establish an IS platform can be increased.

The main conclusion holds that to ensure the minimum viability, an IS platform needs to reduce the risk to be dependent on the co-innovation of firms that will interact on the platform. Currently, too little information about the availability of resources is disclosed and costly innovations are required to publish the information. In addition, firms generally cannot handle new resources as inputs, as it would require them first to adapt their production processes. For asset sharing, there is much less co-innovation risk, since information on assets is easily collected and access to assets could simply replace newly bought assets in existing processes. Because little and no costly innovations are required for asset sharing, the economic barriers to IS are kept low. Moreover, no third-party involvement of specific competence is required, since asset sharing is less complex than other forms of IS. And, finally, asset sharing involves recurrent transactions, which increases the frequency of platform usage, increasing the thickness of the market.

The critical mass is most easily secured by collaboration with an existing industrial network organisation, as it is possible to quickly affiliate a large initial number of firms. Access to assets is relatively standardized, which increases the likelihood of finding matches among the firms within the proximity of an industrial network. Moreover, the platform can leverage the existing foundation of trust that is required for interaction on the platform.

In order to have authority to govern the IS platform and to make firms willing to participate, the owner of the platform needs to have a certain legitimacy. It simultaneously needs to justify its motivation to reduce environmental impact (especially if requesting subsidy by the government), provide a sustainable business model and to confidentially manage the published data. Since a large initial investment is required to reach a critical mass and no sufficient economic incentives exist for businesses to invest, it is unlikely that a digital platform can be established without government support, at least, for the initial stage to cover development costs and initial subsidizing of market participants (e.g., waiving the commission per transaction that users would otherwise pay to a digital platform).

By starting with an MVP for asset sharing, the platform could gradually be expanded with providers of complementary services. In this way an innovation ecosystem could be created, to support IS-enabling innovations. By connecting multiple MVP networks in different industrial parks, larger network effects could be leveraged to be able to match less standardized resources. Together with the provision of consultancy services the IS platform could facilitate by-product exchange, to eventually cover the entire spectrum of IS. Although the results are based on data that is collected in Norway and the Netherlands, these conclusions may be relevant for many other countries.

7.2. Recommendations

As almost all firms are involved in the digitalisation of the industry, coined Industry 4.0, the already pervasive application of digital platforms will likely reach the markets for industrial resources as well. If applied correctly, digital platforms have the potential to enable the transition to a CE, which eventually will benefit all stakeholders. To lead the development of digital platforms for IS in the right directions, the following recommendations are addressed to the Norwegian government, industrial firms, network organisations and service providers.

Norwegian government

For the Norwegian government, supporting IS platforms is a way to promote sustainable development as well as digital innovation. Given the large share of resource-intensive industries in the country, gaining experience in this domain may yield significant spillovers across a multitude of sectors. In order to harness the potential of digital platforms to support IS, there are large upfront risks and investments required from the government. However, considering the commitment of the Norwegian government since 2017 to step up the efforts for realizing a CE (Ministry of Climate and Environment, 2017), the support of IS platforms would already be in line with its current policy. In addition, since Norway may have the best credentials for supporting IS platforms, the country could take the lead in experimenting with such platforms, which would yield valuable knowledge to provide to other countries. Because of these reasons, the Norwegian government is recommended to initiate and support future plans to establish IS platforms.

Industrial firms

The barriers to IS are mainly caused by the underlying behaviour of industrial firms. The acknowledgement of the importance of sustainable sourcing and responsible processing of industrial resources must increase to enable a CE. Besides, the widening of the firms' focus to connect with neighbouring firms and promote the opportunities of trading secondary resources will improve the chances to identify IS potential. Furthermore, as Industry 4.0 will affect any firm, managers are recommended to delve into the mechanisms behind digital platforms, to get informed about future developments.

Industrial network organisations

As linchpins in the networks of industrial firms, the network organisations possess the knowledge and representation to contribute to the development of IS platforms. As prospective users, they are in the position to help shape a platform that would secure the successful adoption by firms. Moreover, as it is in their interest to develop an efficient ecosystem for IS collaboration, industrial network organisations are recommended to exert pressure on the government to initiate the development of IS platforms.

Service providers

Through the potential centralisation of the market for secondary resources, service providers (e.g. transport, law and consultancy firms), would get the opportunity to offer their services much more effectively by leveraging the network effects of an IS platform. However, the success of an IS platform is also dependent on the participation of complementary service providers because they are needed to create an ecosystem that enables the full range of excess resource exchanges. Therefore, firms that are recommended to become familiar with the opportunities that digital platforms provide to come up with innovative business models that support IS.

7.3. Theoretical reflections

As a result of this research, it is now clear why digital platforms, despite the frequently cited opportunities for the CE, are not yet successfully applied in industry. The results also explain to the critics why current platforms have thus far been unable to provide all requirements for supporting IS. It appeared that it is hard to develop an IS platform that serves the full potential of IS, in terms of exchanging the full range of secondary resources, but also serving as both a digital market place and an ecosystem for innovation. Now, with this research, an effort is made to empirically propose a stepwise process for establishing a digital platform to support IS.

The research was not aimed at generating new insights to add to existing theory on IS and the CE since the results are derived from qualitative research on a small sample of cases. However, many of the barriers, interests and criteria that are described in earlier studies are also found in this case study research, which strengthens the value of the empirical results that underlie the conclusions. For example, the need for expert involvement to implement IS came forth several times from the interview data and was described by both Golev et al. (2015) and Benedict et al. (2018). Similarly, data-related trust issues were mentioned by interviewees in both countries, which were already known from those two studies. However, the criteria specific to digital platforms that were identified in chapter 5, such as inducement of users and platform governance, were not found in earlier IS-related research but became relevant by the combination of IS and platform theory in this research.

Due to the new insights on the applicability of digital platforms to solve certain problems in the context of IS, the theory on platforms can be criticized. Much of the mechanisms discussed in the platform theory are operable in the context of a consumer-to-consumer and a business-to-consumer market but are less feasible for the business-to-business market, which is the context of IS. The former two types are for example characterized to be rather thick markets, as there are many consumers, allowing to generate positive indirect network effects more quickly than in business-to-business markets. Moreover, in the business context, there are more requirements set to products and there is more mutual trust involved in the transactions. In addition, markets for the CE are characterized as diffuse markets with unstandardized products, unlike the markets where digital platforms have proven to be so successful. In conclusion, this research has shown that there are more transaction costs and other reasons why digital platforms do not work in the business-to-business and CE context. Although the existing theory explains the dynamics behind digital platforms very well, theories should be deepened. By dividing the development of platform theory into specific contexts, a more nuanced theory would better support research in a specific setting. As digital platforms become increasingly prevalent and are oftentimes regarded to be a solution to many problems, there should be an adequate theory available that is relevant or viable for a problem in a certain setting.

Other theoretical approaches

This research has approached the phenomenon of digital platforms for supporting IS by combining economic theory about platforms with management theory about innovation ecosystems. However, other approaches could have been taken as well, if the emphasis was on other aspects. Benedict et al. (2018) have applied a combination of the theory about business ecosystems and platform ecosystems. In their approach, they allowed a better explanation about the interaction and roles of different actors in the ecosystem, by using the arm's length relationship between the platform and third-party service developers. The continuous development of the services on the platform enables the platform to coevolve with the dynamic IS network itself. Benedict et al. (2018) explain that the

innovation of complementing services will keep the platform up-to-date, by opening the platform up for third-party development of the services. The platform coordinator, or 'broker', "supports the innovation processes in the ecosystem through the mediation and reconnection of service providers and consumers", but, "without offering services on its own" (Benedict et al., 2018, p. 6). The support of the innovation processes occurs through offering boundary resources to the third-party developers. Such boundary resources enable third-party developers to complement the functionalities of the platform, for example through the provision of standardized interfaces, documentation or consulting. By supporting complementary innovation the platform owner achieves a dynamic development of the IS platform (Benedict et al., 2018).

Similarly, the research could have been concentrated on leveraging boundary resources to develop a scalable infrastructure for the process of co-creation between actors in business-to-business platform ecosystems (Hein et al., 2019). The approaches by Benedict et al. (2018) and Hein et al. (2019) do not focus on the role of digital platforms as marketplaces, which, considering the incentives to industrial firms, should be the first role of IS platforms. However, theories about platform economy and innovation ecosystem management are ignored by these authors, which leaves the process of establishing an IS platform from scratch undiscussed.

Another approach could be taken by considering the IS platform as an innovation that needs to be adopted as any other technological innovation. The theory about the diffusion of innovations by Rogers (2010) could be used to describe the process of adoption of the IS platforms in industry. By testing the IS platform against the five attributes of innovations, the success of adoption by industrial firms may be described (Rogers, 2010). For example, the relative advantage (first attribute) of the platform could be the network effects that provide a higher chance of finding valuable matches. However, the trialability (fourth attribute) of the platform innovation may be a major issue, since there is no value to the users when there is no critical mass reached. However, due to several characteristics of IS platforms that are specific to IS and digital platforms, it has been considered to include these characteristics in this research to explore the successful establishment of IS platforms.

7.4. Limitations

The topic of this research is a rather novel phenomenon, on which few empirical data yet exist. However, in-depth insights are generated on the critical conditions for a successful MVP. Because of the novelty of the subject and the prospective nature of interview questions, interviewees might have been unable to link the subject to their experiences, as it might have been the first time that they thought about it. This could have limited the depth of the results. In addition, the interviewer sometimes needed to give examples or suggestions to make the question understandable. Although this has been taken into account, it could have distorted the interview data.

Instead of interviewing Dutch IS platforms, it may have been better if Norwegian platforms were interviewed. But, since there was no running IS platform found in the country, it was chosen to complement the empirical results from Norway with interviews on the experiences from another country. One could argue that the Dutch experiences are incompatible with the findings obtained from the Norwegian organisations, because explanatory factors could be country-specific, such as business relations, culture and policies. However, the phenomenon that has been explored in this research is not that country-specific, as platform dynamics and the CE are universal phenomena. Still, even though the Netherlands and Norway have relatively similar country settings, the barriers, interests and factors identified from the interview data are specific to Norwegian industrial parks.

Therefore, the research could not be replicated in another country to come to the same conclusions, but the conclusions may be relevant to other countries.

Relatively many Norwegian cases are interviewed that gave a representative and clear picture of the barriers, interests and criteria. However, the amount of nine interviews with Norwegian organisations can still be considered as low. Yet, the data collected in Norway are complemented with data from the Netherlands, which confirm the earlier findings and therefore support the results. In addition, the data sample was restricted to the amount of suitable industrial parks in Norway, since it was aimed to interview organisations operating in different industrial parks to get the best representative sample for the Norwegian industrial parks.

By interviewing Norwegian organisations operating at industrial parks (park management organisations, innovation and development organizations, and clusters) this research has tried to approximate a representative sample for identifying the most important factors of supporting IS with digital platforms in Norwegian industrial parks. However, one could argue that the insights of other stakeholders of IS would also be needed to get a complete picture of the subject. Especially, the firm perspective is missed, as many statements are now made by the interviewees on behalf of the industrial firms. Hence, the initial plan was to interview firms as well, but the lack of time, poor respondence rate from approached firms and insufficient proficiency of the Norwegian language hindered the interviewing of a valuable number of industrial firms.

Lastly, the three Dutch interviewees are interviewed about their experiences with the platforms, but the functioning of those platforms are not investigated extensively. This could result in self-reported data, which have not been evaluated by the researcher.

7.5. Follow-up research

This explorative research has proposed a stepwise process for establishing a digital platform to support IS. Future research could elaborate on the findings, focus more on particular parts of the subject or extend the insights to other contexts.

- Follow-up research covering empirical data from more kinds of Norwegian stakeholders of IS could probably give other insights that might be valuable for refining the proposed process for IS platform establishment. By interviewing industrial firms, the Norwegian government and service providers, a more complete understanding of the potential for IS platforms can be obtained. Similarly, the stakeholders involved in the two platforms in the Netherlands can be valuable to interview.
- By narrowing the focus on existing platforms, more insights should be obtained about the process of IS platform establishment in general. The country setting would be irrelevant in such research, as the currently running IS platforms are located in many different countries.
- In this research, there is a distinction made between the applicability of asset sharing and by-product exchange for the MVP, based on a couple of specifications in favour of asset sharing. However, within the range of by-products, there are large differences of suitability for trade through an IS platform. Therefore, by investigating what by-products are easy to trade, that are abundant, standardized, easy to control on quality, it can be identified which by-products qualify to be traded first in order to improve the success of the adoption.
- Future research could also extend the insights from this study to other empirical contexts, as the same principles could be used for markets in other settings. Especially, settings would be relevant with on the one hand relatively standardized products and on the other hand high

transaction costs, which can be reduced by the platform. Regulations are often the cause of high transaction costs, especially for SMEs, as it takes much effort to comply with the diversity of rules. This context could be promising for future research into the opportunities for digital platforms to facilitate trade.

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Appendix 1. Interview guide

Interviews with industrial organisations (O1, O2, O3, O4, O5, O6, O7, O8, O9 and O10)

Interviewee background

- What is your current position in “the organisation”?
- What is your background and experience?
- For how long have you been working at “the organisation”?

Organization characteristics

- What does “the organisation” do?
    - What are the services you provide?
- When was the organisation founded?
- What was the motivation for establishing “the organisation”?
- How does the organisation work?
    - Management
    - Departments
    - Projects
    - Communication channels with organisations in the park

Industrial park characteristics

- How many organisations are located in the industrial park and what is the geographical scale?
- In what industrial sectors are the organisations operating in?
- Is every organisation in the area included in the park?
- What kind of relationships or links exist among organisations?
- What are the main environmental concerns?
    - Is this coordinated by “the organisation”?
- How is external (expert) knowledge gathered?
    - Is this facilitated by “the organisation”?

Current situation

- Is there any form of resource exchange? Like water, energy, by-products.
    - How is it coordinated? Are there any tools (e-mail, shared folder, contact person, Whatsapp, etc.)
    - Is it monetized?
- How is dealt with underutilized assets? Like machines, vehicles, infrastructure, personnel, expertise, storage space, etc.
    - Is there any form of exchange of these assets? How?

        - How is it coordinated? Are there any tools (e-mail, shared folder, contact person, Whatsapp, etc.)
        - Is it monetized? (rent/exchange/shared costs)
- Have you ever thought about another way to coordinate the exchange of excess resources and underutilized assets? What/Why not?
- Have you thought about an online platform? Why (not)?
- What are current barriers for resource and asset exchanges?
- How are networks/relationships/links between firms set up until now?
- What are the important factors in building such networks?
- Why these factors?
- How is the trust of firms in "the organisation"?

Introduction of an Industrial Symbiosis platform

Potential IS platform ecosystem

- What kind of issues that you currently experience could be solved by this online platform?
- How would the trust change in "the organisation" when it would act as a coordinator in an IS platform?

Information & knowledge exchange

- What do you think will be the willingness of companies to share information and knowledge in terms of:
    - Mutual trust? (risk on misuse of information)
    - Confidentiality? (sensitivity of information, non-disclosure)
    - Motivation? (unknown potential profits)
- What do you think will be the ability of companies to share information and knowledge in terms of:
    - Difficulty? (difficult to communicate expert knowledge)
    - Relationships? (absence of contacts with information/knowledge)
    - Availability? (lack of information about own material flows / used capacity)
    - Understanding? (lack of understanding and poor communication)

Adoption factors

- What could be your main interests in participating in an Industrial Symbiosis platform?
- What would be your criteria to adopt the platform?
- What do you expect the answers on the last 2 questions would be from industrial firms?
    - What kind of firm would participate in such an online platform? Why?
    - What not? Why?
- What do you think this platform could mean for new business creation and innovation?

Minimum Viable Ecosystem

- What kind of resource exchanges in your industrial park do you think are easiest or hardest to establish via a digital platform?
- What stakeholders do you think are the most important or influential in an Industrial Symbiosis platform ecosystem in your industrial park?
- Which stakeholders are crucial for establishing this Industrial Symbiosis platform ecosystem in your industrial park?

Further engagement

- Do you think that a Industrial Symbiosis platform would be beneficial for "the organisation" in the future?
- What do you expect to be the attitude of firms in your industrial park to an Industrial Symbiosis platform?
- What do you think that would be the right geographical scale for such a platform? Park/region/country/…
- Would you be interested to be involved in an Industrial Symbiosis platform?

- Would you like to add something to the subject? Does something else come up in your mind?

Thank you for the interview!

Interview platform provider

Background

- What is your role at 'the platform'?
- How long do you work at 'the platform'?
- What is your background?
- What does 'the platform' actually do?
    - How big is the project?
- Why is 'the platform' founded?
- How does 'the platform' work?
    - How are the firms matched?
    - What are the functionalities of the platform?
    - Who builds the software?
    - What is the revenue model?
- What is the current status of the platform?

Organisation of the platform

- What actors are involved in the platform? Owner, investors, industrial park management, advisory firms, etc.
- What collaborations are there between these actors?

Platform establishment

- What are the most important reasons for firms to use the platform?
- What are the most important criteria that the platform must meet?
- What stages are there for establishing the platform?
- What have been the most important barriers for establishing the platform?

Facilitation of industrial symbiosis

- What matches are made through the platform and how did this occur?
    - What is the ideal procedure?
- What are differences between using the platform for asset sharing and by-product exchange?
- Which what kind of exchanges did the platform start and why?
- What firms where the first movers and why them?
- What are the barriers in facilitating IS through the platform?

Information sharing

- What kind of data are firms asked to publish on the platform?
- What is the role of trust / confidence on the sharing of data?

Growth and success

- Does the demand for the platform's service grow?
- Are there functionalities that could be added to the platform to further support IS?

Lessons learned:

- Which parts of the platform are successful and which no?
- What would you have done different?
- What is your opinion on the role of digital platforms in facilitating IS and achieving a CE in the future?

- Would you like to add something to the subject?

Thank you for the interview!

Appendix 2. Description of interviewees: Norway

O1 - Mo Industripark

Jan Gabor is the vice-president marketing and business development of Mo Industripark (MIP). This organisation is the property owner to more than 100 tenants that are located in the industrial park, spreading over about 300 hectares. It owns and maintains the buildings and the infrastructure and it distributes water and heating within the park. The industrial park used to be one large state-owned company, which in 1989 split up and divided in the private companies of today. The main industrial sectors in the park are the metal and mining industry. There are about 8 larger companies with more than hundred employees and those are surrounded by smaller firms adding up to 2600 people in total. MIP Sustainability is the department that is responsible for projects related to environmental concerns, with three focal areas: energy, recycling and emission. The organisation tries to find new opportunities within these areas through feasibility studies and by connecting firms to find solutions. To bring in competence there are partnerships with an industrial cluster (Arctic Cluster Team) and several research and innovation institutes, such as Sintef and universities. Mo Industripark is leading in Norway when it comes to IS. The companies have a long tradition of material and energy exchanges and have formed an industrial ecosystem.

$O2_1$ and $O2_2$ - Thams Cluster & Næringshagen i Orkdalsregionen

John Kåre Solem recently became the manager of the in 2018 established Thams Cluster, consisting of the managers of the firms located in Orkanger. The cluster has the goal to increase the competitiveness of the firms and to provide a platform for facilitating and identifying new projects within the area of the circular economy. The cluster is organized in different competence groups, with each working at different topics. The main industrial activities are the process, nutrition and oil industry. The firms are already undertaking various IS projects where they mainly exchange by-products, but they ask for insights in opportunities for further collaborations. Therefore, the Thams Cluster is in preparation of a new project where they plan to establish a digital tool containing real-time data about the resource flows of the companies to facilitate the identification of new IS projects.

Morten Solstad is a business advisor at the Næringshagen, which is an organisation that supports the development and innovation of businesses in the Orkdal region. Depending on the success of the new project, Morten will be a manager for projects resulting from the IS tool and for firms that are interested to join.

O3 - Kongsberg Teknologipark

Frank Andersen works for 13 years as the operating manager at Kongsberg Teknologipark. The organisation owns the buildings of all the 40 companies that are located in the industrial park and runs the facilities, except the canteen and cleaning services. The services consist of maintenance, security, energy distribution and management of building projects.

The industrial park is established in 1814 as a large weapon producer, but split up in 1987 into separate companies of which Kongsberg Teknologipark owns the facilities. Nowadays, the companies are not very connected anymore and are specialized in different industrial areas, such as defence and aerospace technology. The main environmental concern is the handling of electronical waste and their goal to become fully circular. Kongsberg Teknologipark is in charge of collecting the waste, but

they deliver it to a waste management company. As far as O3 knows there is no IS taking place between the firms in the park, except for some exchange of personnel and heat recovery.

$O4_1$ and $O4_2$ - Skogmo Industripark

Ola Lauve and Marius Ness Huseklepp are two of the four project leaders working at Skogmo Industripark. This organisation has the task to support the 50 member-firms, mostly on project basis, with things like organisational development, product innovation, sustainability and nowadays a lot with digital transformation. The firms are varying in size between one and 160 employees and are mainly active in the process industry and construction branch. The organisation was established to serve as an arena for cooperation between the companies to increase their competitiveness. Skogmo Industripark is owned by the 30 of the member-firms that are located in the main equally named area. Some of them members are located 50 to 60 kilometres away, but they do not belong to the core. The organisation supports the firms in organizing their challenge to reduce their environmental footprint.

Skogmo Industripark actively promotes new ways of thinking to enable a circular economy in the area. An example is a recent project where they provide a car to the firms which is available for shared usage. There are no exchanges of by-products that are worth mentioning, but according to Ola Lauve there is more potential for asset sharing among these companies. There has been a project with a digital tool for sharing of excess personnel between different construction companies, but due to equal seasonal needs it did not take off.

O5 - Proneo

Viggo Iversen is the head of the advising department of Proneo. Proneo is an innovation consulting company operating in the county Trøndelag. Verdal Industripark is an industrial area for which several actors collaborate in the management: Proneo, Verdal municipality, Verdal business forum and Verdal business association. In this collaboration Proneo is responsible for business consultancy for the approximately 200 firms that are located here. The firms are operating in the construction, mineral and nutrition industry. Except from some examples where companies share production facilities and personnel, IS is not an import focus in Verdal Industripark. However, Viggo Iversen is also involved in a project in Fiborgtangen, another industrial site in the county, where a project is planned to do a resource mapping of the surrounding area. The goal is to research the opportunities to intensify the already existing IS of Fiborgtangen.

O6 - Industrial Green Tech

Irene Vestby is the cluster manager of Industrial Green Tech, which includes 32 member firms in the region Grenland, including Herøya Industripark. The firms are mainly operating in or supplying to the petrochemical industry and have gathered into the cluster to reach faster implementation of technology in order to reduce greenhouse gas emissions from the industry. The ambition is to be the world's first climate positive industrial region and to deliver green technologies to the global market of industry. The four focus areas of the cluster activities are, product and process development, industrial circular economy, logistics and infrastructure and the regulatory framework. The cluster provides an arena where the firms can meet to discuss common challenges and to concretize specific projects. Sintef and the University of Southeast Norway are also members in order to bring in external knowledge for stimulating more research and development in the region. Digitalisation of industrial processes is one of the focus areas and is considered as means to increase efficiency and the reduction of emission. The firms in the cluster are already engaged in many IS projects, which are supported by working groups organized by the cluster.

O7 - Sintef Manufacturing / Catapult Centre

In 2006 started Emma Østerbø working at Sintef Manufacturing, which is leading the industrial cluster Norwegian Centre of Expertise (NCE) Raufoss, consisting of 17 companies counting 5000 employees. However, since November 2019 Emma Østerbø is rented out by Sintef as the daily manager of an new organisation called Manufacturing Technology Norwegian Catapult Centre (MTNCN). This organisation is funded by the Norwegian government to serve as a national test facility for manufacturing firms that can come here to test their concept with the equipment of the MTNCN, so that they can later on invest in their own factory. Firms that have excess capacity can offer this through the MTNCN to firms that need test facilities. They also serve as an arena for research and development in collaborative projects for the approximately 50 firms in Raufoss.

Like several other industrial parks, the firms in Raufoss used to be one state owned company that separated in different firms are nowadays mainly operating in the defence and automotive market or spin-offs from both. The firms in Raufoss operate in a very cooperative environment, with much investment in building a strong network and sustainable projects. Apart from sharing capacity through the MTNCN, Emma Østerbø does not know about any resource exchanges.

O8 - Norwegian Centre of Circular Economy

The Norwegian Centre of Circular Economy (NCCE) is a centre for the development of new circular business opportunities for the Norwegian industry. Camilla Brox is initiator and CEO of the NCCE and offers solutions and a network to support firms that see opportunities in the circular economy and the sustainability transition. The organisation has national ambitions to offer firms a starting point for projects, from where they can map the opportunities and challenges. In fact, the NCCE is a cluster organisation with 49 members spread over an area focused on Friedrikstad, and Øra Industripark in particular.

The NCCE has the goal to build a digital market place for the circular economy, but this is only in the ideation phase. They are still trying to find a business strategy for this market place. The plan is to start with the mapping of resource flows, after which they will look for partners to develop the project. Because of the many successes of the NCCE in developing circular projects O8 thinks the management is ready for such a project.

O9 - Arctic Cluster Team

Monica Paulsen is the cluster manager of the Arctic Cluster Team (ACT) since it was established in 2017. This cluster originated from the wish from firms to partner up in the sustainable transition after a successful collaborative innovation project between four large metal producers in Helgeland, in the north of Norway. The cluster started with 40 firms and grew to a total of 60 firms operating in different parts of the process industry and spread over the northern part of Norway. By organizing cluster events and specific workshops they support the innovation capacity and competitiveness of the member firms. The cluster program receives governmental funding because it is helping Norway to fulfil its obligations to the Paris Agreement.

Industrial symbiosis is one of the themes that the cluster works with, which resulted in a project plan to build a digital lab to use for identifying IS, based on the industrial ecosystem in Mo Industripark. The ACT applied for governmental funding for the project, but didn't succeed after which the project ended.

Appendix 3. Description of interviewees: the Netherlands

P1 – Floow2/Parksharing

Laury Zwart co-founded Floow2 in 2012. Within the organisation she is responsible for the marketing and communication, but since recently also for business development and project management. Floow2 is a software developer for b2b sharing platforms, on which organisations and departments can share materials, services, facilities, knowledge and personnel among each other. They started focussing in the construction sector with underutilised heavy equipment and expanded to other sectors from 2014. Their new project, Parksharing, started in 2018 and is focussed on industrial parks to support by-product exchange and asset sharing between firms within and across industrial parks. The project is a collaboration between Floow2 and Solaris Parkmanagement, which manages a number of industrial parks in the Netherlands. Another organisation, called Symbiosis4Growth, is involved in the platform as a consultancy actor, especially concerning by-product exchanges.

Municipalities or industrial park management organisations can approach Floow2 to develop a customized platform for the firms they want to facilitate, often with financial support from the government. The firms are offered to use the platform without costs for short period (e.g. one year) to try it out and encourage the usage. After this trial period, the firms have to pay a fixed access fee per month to be able to make their demand and supply transparent on the platform. Already more than 1500 firms have an account on the platform and many matches are made.

O10 – Solaris Parkmanagement

Frenky van Gool is junior parkmanager for three years at Solaris Parkmanagement and is involved in the Parksharing project. The organisation manages 36 industrial parks, from which 6 have Parksharing platforms. The platform is one of the services that Solaris Parkmanagement provides to the tenant firms located on their parks. The organisation noticed that all firms were considering sustainability, but no firm had a clear and practical way to transform its activities. The collaboration with Floow2 started the emphasis on the CE and the platform is aimed to serve as an easy and compatible tool to engage in IS.

Because the firms are already connected with the parkmanagement organisation, Solaris is able to communicate about Parksharing by promotion and giving instructions. However, Frenky notes that the service of platform is still not in the system of many firms and there is still a need for constant repetitive reminding of the firms to change their fixed behaviour. The platform is mainly used for asset sharing between the firms located at the same industrial park.

P2 – Stichting InduSym

Immanuel Geesing is a sustainability consultant and the creator of InduSym, an open platform for firms to demand, supply and share industrial materials and assets. During his post master at the TU Eindhoven he researched IS, which resulted in a project to establish a sharing platform. In collaboration with Stichting Bedrijventerreinen Helmond (SBH), a park management organisation, and Twinvision Software, an IT company, they developed the platform that what launched in 2017. The platform is created as a tool that SBH could use to facilitate IS matching among the firms located at the industrial park, but is now turned into an open platform for all firms that want to be involved. The platform is now owned by a foundation with a daily board consisting of Immanuel and two

representatives from SBH and Twinvision Software. Two freelance consultants are working for the foundation to facilitate the IS resulting from the platform. The primary goal of Stichting InduSym is to support SMEs in the transition to a circular economy.

Firms that are interested in participating in the platform can create an account for free and log in to offer and request secondary materials and assets. An algorithm then matches the firms in the network, who can then negotiate and settle the transaction themselves. However, to collect data for the platform, the foundation developed a 'materials-scan', a paid service that is offered to firms or park management organisations to identify opportunities for IS. Resources that cannot be matched within the direct network of the consultants will be placed on the platform. Approximately 250 firms have actively signed up for the platform.