THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

PATTERNS OF RESOURCE INTERACTION IN RESOURCE CONSTELLATIONS:

The case of start-ups approaching the Swedish energy system

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ABSTRACT

This doctoral thesis deals with resource interaction in business networks. Interactive resource development is based on a combination of new and existing resources. However, interactions with specific resource constellations will look different depending on the context in which a new resource is to be embedded. Consequently, to support technological development and innovation it is important to understand how resources interact in a resource constellation and how changes evolve when to make new resources useful in the business network.

Therefore, the aim of this thesis is to develop the understanding of resource interaction in business networks. The theoretical starting point is the Industrial Network Approach to industrial markets, especially resource development through interaction. Particular attention is devoted to the resource interfaces that are created between the resources of start-ups and those of other actors in the business network, and the way these are combined to create value for the involved parties over time.

The empirical setting of the study is the Swedish energy system, which is characterised by long-term business relationships and investments and an urgent need for transformation. The method used is a single case study that describes the innovation journey of three start-ups when approaching resource constellations. The three start-ups focus on novel approaches to renewable energy.

The results of this thesis are manifold. Firstly, the study contributes an analytical model to capture connected resource interfaces in business networks and identify potential hindrances and enablers when embedding new resources into a resource constellation. Consequently, different sequences of connected resource interfaces will occur, forming different resource interaction patterns. Five patterns are identified that can help in estimating the effects of attempting to embed a new resource into a resource constellation. Secondly, the study reveals that exploring the potential versatility of a resource in a resource constellation is a matter of exploring and exploiting resource interfaces within it. Thirdly, the study emphasises the importance of considering not only the known use(s) of a resource but also its potential use(s).

Regarding policy implications, it is important to consider the network of the start-up when investing in start-ups that could be part of transforming the Swedish energy system. It is important to assess the resource collections of a start-up and the potential resource constellation it would be part of to see if any existing resources could act as a ‘bridge’ to the energy system. From a start-up manager’s perspective, it is important to have an awareness of the process of working with certain resource interfaces and how they are connected in order to allow for a start-up’s resources to be embedded into the business network. It is also necessary to find collaboration partners that are willing to make adaptations to their own resource collections.

KEYWORDS
Business Networks, Resource Development, Interfaces, Start-ups, Swedish energy system

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Maria Landqvist
Gothenburg, 2020

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“Almost every time I meet someone new, whether it is an end-user or a partner, I learn something new. That’s why we have said that it is important to continue meeting new actors”

– CEO of Aqua Robur

1. Introduction

This thesis deals with resource interaction in business networks. The empirical setting is the Swedish energy system, especially how it is approached by start-ups. Below is an introduction to the thesis, first in the theoretical context and then the empirical one. This is followed by the aim and outline of the thesis.

1.1 Interactive resource development in business networks

Technological development and innovation, in broad terms, have been studied as interactive phenomena with a basis in the Industrial Marketing and Purchasing (IMP) tradition for decades. The focus of these previous studies has been on interaction and business relationships in business networks. For instance, empirical studies have illustrated collaborative technological development processes (Håkansson, 1989; Laage-Hellman, 1989) and, more recently, focused on interactive resource development (see e.g. Baraldi, 2003; Holmen, 2001; Håkansson & Waluszewski, 2002a, 2007; Ingemansson, 2010; Wagrell, 2017). Holmen (2001), for example, studied the development of a new product by looking at how it is embedded in a resource structure, emphasising the importance of interactions across firm boundaries in exploring other firms' resource collections. Baraldi (2003) studied the effects of IT on resources and how the value of IT depends on how it is embedded in relation to other resources such as products and business relationships. Ingemansson (2010) investigated the commercialisation of pyrosequencing, especially the resource combinations required in transitioning from science to business.

Resource development can be seen as the result of combinations of new and existing resources with the aim of developing new useful ones. In order to create a new and useful resource, existing resources located within a firm need to be combined with those beyond the firm's boundaries. Moreover, the resources need to function in different settings; both in a producing, developing and using setting, in which they need to fit with existing resources (Håkansson & Waluszewski, 2007). In other words, to generate business and start growing, firms need to become established in business networks by developing relationships with customers, suppliers and other types of business partners.

The processes of embedding resources into specific resource structures will look different depending on the context. For example, an existing resource structure, comprised of several combined resources located both within and across firm boundaries, could have been developed over a long time and for a specific purpose. Hence, the existing resources are adapted to be useful in certain combinations and thus it could be costly to disconnect and adapt them to facilitate the integration of a new resource with the existing structure. This dynamic could be referred to as a 'heavy' resource structure (Håkansson & Waluszewski, 2002a), and in order to embed a resource into a 'heavy' resource structure it is important to understand how existing heaviness can be taken advantage of. As Håkansson and Waluszewski (2018, p. 274) state: "*heaviness of established producing and using settings is a policy blind spot [...]. The contemporary policy analytical frameworks lack the ability to identify aspects that all innovation attempts have to relate to, that economic heaviness of related producing and using settings will kill many of them, that it will open up possibilities for some of them to prosper, and perhaps most importantly, that it will force all innovation attempts to take directions that are beneficial for the main part of established, heavy producing and using setting."*

Consequently, to support technological development and innovation it is important to understand how resources interact in a resource structure and how changes occur when new resources are embedded into existing business networks (Håkansson & Waluszewski, 2002a, 2007). However, more empirical studies on resource interaction are needed to refine key concepts to capture resource interaction from a multi-actor perspective (Baraldi, Gressetvold, & Harrison, 2012; Prenkert, Hasche, & Linton, 2019). Specifically, it is important to expand the analysis from individual relationships to the network level by including connected relationships (Baraldi & Strömsten, 2006). Therefore, this thesis intends to deepen existing knowledge of resource interaction and how changes occur in resource structures.

This study explores how new resources become embedded in business networks, with particular focus on resource structures (Håkansson & Waluszewski, 2002a), by studying focal resources introduced by technology-based start-ups. The start-ups are founded at universities, and their ideas stem from both researchers and companies. Collaboration with external partners is particularly important to technology-based start-ups, as they often lack significant resources (Antolín-López, Céspedes-Lorente, García-de-Frutos, Martínez-del-Río, & Pérez-Valls, 2015; Baum, Calabrese, & Silverman, 2000; Coviello & Joseph, 2012). Developing business relationships with other actors in the business network is important for commercialising ideas and making focal resources valuable to other actors' resource collections (Aaboen, La Rocca, Lind, Perna, & Shih, 2017; Baraldi, Havenvid, Linné, & Öberg, 2019).

One particularly interesting setting in which start-ups try to establish is the Swedish energy system. By trying to develop new renewable energy technologies, the start-ups will take part in transforming the system into one that provides 100% renewable energy. Hence, start-ups' efforts to embed their focal resources into the resource structure of the Swedish energy system are used to create an understanding of resource interaction in business networks. Next, the empirical setting of the Swedish energy system is presented.

1.2 The empirical setting: the transformation of the Swedish energy system

The Swedish energy system is currently facing the challenge of achieving 100% renewable electricity production by 2040 and zero greenhouse gas emissions by 2045[1]. This is the result of an ongoing worldwide discussion on the relationship between economic development and environmental degradation. In 2015, an agreement was reached between 195 of the world's countries to mitigate global warming[2] as a result of a 40-year attempt to bring awareness of the issue to world leaders, starting with the UN Conference on Human Environment in 1972 in Stockholm.

The Swedish energy system could be considered to be performing well compared with other energy systems around the world since it already includes 25% renewable energy sources. Additionally, hydropower, which is considered the linchpin of the system, constitutes 11% of the energy sources used[3]. However, there is still a need to phase out oil and possibly nuclear power to achieve a 100% renewable system. Nevertheless, by being at the forefront of this transformation, Sweden could act as a role model for other countries on how to create a sustainable society. This is not a change that will occur overnight; it requires the joint efforts of the actors in the current energy system, stretching from those supplying the sources of energy, transforming it into electricity and fuels, to those distributing and using it in the end. Additionally, it will put demands on actors outside the conventional energy system and force politicians to create new regulations to facilitate the entry of new technologies into the system. As the framework of agreement between five of the largest political parties stressed in 2016[4]: *"There need to be better prerequisites for investing in renewable energy technology […]. The development of the energy system should take the starting point in a diversity of large-scale and small-scale renewable [electricity] production that is adapted to both local and industrial needs."* Furthermore, the agreement

[1] Miljö-och energidepartementet, 'Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna', *Regeringen.se*, 2016, https://www.regeringen.se/contentassets/b88f0d28eb0e48e39eb4411de2aabe76/energioverenskommelse-20160610.pdf
[2] United Nations, 'The Paris agreement', *unfccc.int*, 2018, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[3] Statens energimyndighet, 'Energiläget 2017', 2017
[4] Miljö-och energidepartementet, 'Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna'

concluded that technology development plays an important role in this transformation and thus existing regulations should conform to new products and services.

However, bringing new technology into the Swedish energy system and thus transforming its current character is not easy. As Jacobsson and Bergek (2004) pointed out already 15 years ago, the problem is not the potential of renewable energy technologies but how these can be realised and adapted to what already exists in order to contribute to the transition from fossil fuels to renewable energy. Negro, Alkemade, and Hekkert (2012) talk about an inert system resulting from a strong interrelatedness between the energy and economic systems and the problem of overcoming the so-called 'valley of death' (see e.g. Markham, Ward, Aiman-Smith, & Kingon, 2010). Hence, renewable energy technologies have difficulty breaking into the energy market, which is dominated by fossil fuel technologies and benefits from economies of scale and having had long periods of technological adaptation and learning. Moreover, national energy industries worldwide consist of a small number of large players including distribution companies, regulators and grid operators, and most policies do not favour new technologies (Sen & Ganguly, 2017). Consequently, several studies have been carried out on how new renewable technologies can enter the energy system (see e.g. Andersson, Hellsmark, & Sandén, 2018; Mignon & Bergek, 2016; Sagar & Van der Zwaan, 2006), stressing the importance of creating policies to support new innovations. Still, there is a problem in not letting small innovative firms take part in designing new policies, as they are often neglected in favour of the large actors in the system (Negro et al., 2012).

Looking at Sweden in particular, one step in the right direction was taken in 2017 when the Swedish Energy Agency gathered a wide range of representatives from private and public companies, municipalities and county councils to discuss strategies spanning different sectors, rather than just the conventional energy system[5]. Moreover, the Swedish Energy Agency has started to focus on supporting start-ups as a group of actors that can bring new renewable technologies into the energy system. Up to now, approximately 200 small and medium-size firms[6] have been financed, and there is a call to develop the financial tools and processes for deciding which start-ups to invest in. There is growing interest in better understanding and evaluating the potential role of start-ups and the possibilities for making their ideas useful in the future energy system. The following section introduces the Swedish energy system as a business network. By doing so it is possible to analyse start-ups' resource

[5] Statens energimyndighet, 'Sektorsstrategier för energieffektivisering: Sverige ska bli världsbäst på energieffektivisering', 2018
[6] Interview with a business developer at the Swedish Energy Agency, 2018-12-11

interaction in the business network and particularly the process of embedding their focal resources into the resource structure of the Swedish energy system.

1.2.1 The Swedish energy system as a business network

The Swedish energy system comprises many organisations, such as companies and authorities, of which some are more closely linked than others. Even though some would argue that the energy system has historically been built by actors that prefer to optimise their own processes to cooperating for better solutions, there are some historical examples of collaboration that has led to major changes in the system. For instance, the Swedish energy system seen today has its foundation in several inter-firm business relationships. A central one, between Vattenfall and former ASEA, enabled large-scale production of electricity by developing the first 380 kW power line between Harsprånget hydropower station and Hallsberg in the 1950s (Kaijser, 1994). Another more contemporary example is the cooperation between Vattenfall, E. ON and Svenska Kraftnät, the purpose of which is to find common solutions to the issue of balancing the increasing user demand for electricity with an undersized grid system[7].

While there are buyers and sellers in the system that are linked through economic exchange, there are others that are linked through interactions in other areas. The latter is a situation that has been common during the phase of transforming the system to develop new technical solutions. For example, the oil company Preem collaborates with different research facilities to develop sustainable substitutes for fossil fuels, and E.ON looks for potential development partners outside Swedish borders to facilitate the development of local energy systems[8]. Moreover, actors such as start-ups that want to enter the energy system collaborate with different partners to develop new renewables technology. Consequently, for analytical purposes the Swedish energy system could be seen as a business network comprised of actors connected through business relationships (Håkansson & Snehota, 1995). Specifically, the Swedish energy system is built on a resource structure containing several sub-structures, for example power plants and grid systems. Bringing new resources into the resource structure to enable the development of new renewable energy technology requires resources to be embedded into developing, producing and using settings, and thus collaboration among several actors in the network (Håkansson & Waluszewski, 2007).

[7] Svenska Kraftnät, 'Nytt samarbete för smartare användande av elnätet', *via.tt.se*, 2018, https://via.tt.se/pressmeddelande/nytt-samarbete-for-smartare-anvandande-av-elnatet?publisherId=1035173&releaseId=3242652
[8] E.ON, 'Keep track of the local energy system – for real', *eon.se*, 2020, https://www.eon.se/en_US/om-e-on/local-energy-systems/live-from-simris.html

1.3 Aim and outline of the thesis

The aim of this thesis is to develop the understanding of resource interaction in business networks. Particular attention will be devoted to the resource interfaces that are created between start-ups and other actors in the business network, and the way in which resources are combined to create value for the involved parties over time. Furthermore, the ways in which existing and new interfaces are developed through interaction and in relation to resource structures will be analysed. Resource interfaces (Dubois & Araujo, 2006; Prenkert et al., 2019) play an important role as they are the contact points at which two resources interact and where features are adapted to create a good fit between them in the resource structure. The empirical setting of study is the Swedish energy system, especially how technology-based start-ups approach the Swedish energy system. By focusing on the early stage development of start-ups, and consequently the initial business relationships that they develop, it is possible to describe and analyse the development of business relationships and the process of starting up in business networks (Aaboen et al., 2017). Hence, start-ups' efforts to become part of the business network are used as a means to understand *resource interaction* as a phenomenon in business networks.

To achieve this aim, a qualitative method is used to study start-ups originating from the incubator linked to Chalmers Ventures. Aaboen, Dubois, and Lind (2011) suggest that longitudinal case studies are suitable in efforts to develop an understanding of the formation of initial relationships. Capturing start-ups' relationships in the business network over a period of time makes it possible to follow their interaction with counterparts and identify critical steps in the establishment process.

The thesis is structured as follows. After the introductory chapter, the theoretical frame of reference, including the theoretical concepts linked to the Industrial Network Approach, is presented. The chapter ends with a problem discussion and research questions. The methodology of the study is then introduced, followed by the case study 'Starting up in the Swedish energy system', including three sub-cases and a sub-case analysis. In this section several resource interaction patterns are identified. Thereafter, the findings from the sub-case analysis are discussed, firstly in relation to the concept of versatility and the exploration of the versatility of a resource in a resource constellation, and secondly with regards to the resource structure of the Swedish energy system. The thesis ends with a concluding discussion and suggestions for further research.

2. Theoretical frame of reference

This chapter introduces the theoretical frame of reference of the thesis and three research questions. To be able to fulfil the aim of developing the understanding of resource interaction in business networks, the theoretical framework includes three parts in four different subchapters. Firstly, an introduction to the theoretical underpinnings of the Industrial Network Approach and how they relate to other approaches to innovation and resources is presented. Secondly, resource development in interaction and particularly resource interfaces is introduced. Thirdly, the chapter ends with an analytical framework and research questions.

2.1 An interactive view on business markets

The study takes its theoretical starting point in the Industrial Network Approach (INA) to industrial markets, also referred to as the Industrial Marketing and Purchasing (IMP) research tradition. IMP has its foundation in several empirical studies on buyer-seller relationships conducted in the mid-1970s and early 1980s. The studies were a result of the limited use of existing frameworks that explained common phenomena in business markets, and they showed that there is more than just economic exchange between companies. In contrast to the more traditional view of marketing, i.e. seeing the industrial market as generic and constituted of a group of actors reacting to certain stimuli, the first IMP study revealed empirical observations of long-term business relationships between two *active* parties, the buyer and the seller, and a market characterised by stability rather than by being subject to change (Håkansson, 1982). The reason for this was related to several factors, such as the desire to avoid transaction costs when changing suppliers, the need to simplify the handling of many suppliers and decreasing the negative effects a change would have on other actors' business relationships. These findings opposed the concept of the independent firm that moves freely within the market with no transaction costs and perfect knowledge of potential outcomes, i.e. the cornerstone of traditional economic theory. Instead, markets may function inefficiently because of human and environmental factors and, as Williamson (1979) emphasised, complexity and uncertainties may lead to costly negotiations between parties and therefore difficulties in changing partners. Thus, there was a need for new frameworks that could analyse and describe the nature of buyer-seller relationships on industrial markets.

In order to analyse what happens between two companies that interact on industrial markets, Håkansson (1982) suggests four crucial variables included in the 'interaction model': (1)

the companies involved in the interaction and the different components related to them, such as the size of the firms, the technological systems belonging to them and previous experience; (2) the elements and process of the interaction, such as the episodes developed within the relationship and the elements of exchange; (3) the environment in which the interaction takes place; and (4) the atmosphere influencing the interacting companies. Ford (1980) also emphasises that the interaction between two companies is influenced by previous experiences in the relationship and the expectation of future activities. Consequently, the relationships are both resources and burdens for the firms involved.

The second IMP study went deeper and explored what constitutes a business relationship and how a relationship affects other relationships, resulting in a network of interconnected relationships (Håkansson, 1987). Taking the activities related to industrial technological development as the starting point shows that this is not an outcome of only one actor's internal product development activities but depends on the interaction between several actors and their resources. Thus, the business market was conceptualised as an industrial network (or business network) composed of three important parts: firstly, the *actors* involved in the relationships, namely the companies themselves; secondly, the *activities* performed by the actors; and thirdly the *resources* used to perform the activities. The activity links, resource ties and actor bonds in the business relationship influence not only the activity structures, resource collections and organisational structures belonging to the firms involved in the relationship but also the activity patterns, resource constellations and web of actors belonging to the network as a whole (Håkansson & Snehota, 1995). Moreover, when studying the adaptations that take place in a business relationship, it is evident that these adaptations affect firms indirectly connected to the specific relationship. Anderson, Håkansson, and Johanson (1994) refer to this as 'connectedness' between firms, which underlines the importance of considering not only the positive and negative effects of the relationship on the two firms but also the indirect effects caused by indirect relationships. Each business relationship has what Håkansson and Snehota (1995) refer to as a 'network function' in terms of affecting other relationships and actors in the business network. Thus, a change in a relationship can have effects on three levels; (1) on the specific relationship, (2) on the companies involved in the relationship, and (3) on the network.

The three layers of actors, activities and resources deserve a closer look. Firstly, the activity layer consists of internal activities that are linked within the company as well as with the actors in the network and, as a result, form activity patterns (Håkansson & Snehota, 1995). By adjusting the activities inside as well as outside the firm's boundary to improve joint performance, interdependencies between activities are created (Dubois, 1998; Gadde, Håkansson, & Persson, 2010). It is important to emphasise that the process of linking the activities of two companies requires both adaptation and formation of routines (Håkansson

& Snehota, 1989). Secondly, in the resource layer, the resources are combined either as a collection of resources within the company or between the different actors as resource constellations connected through resource ties (Håkansson & Snehota, 1995). Resources are also confronted, adapted and combined. The value of a resource is therefore dependent on how it is connected to other resources (Håkansson, 1987; Håkansson & Waluszewski, 2002a). Thirdly, the actors themselves are connected in a web of actors that forms a network through the actor bonds (Håkansson & Snehota, 1995). Accordingly, there are restrictions when it comes to autonomy and control in the business network because the companies need to adjust to each other's processes. Thus, it can be concluded that no company works in isolation but is dependent on other companies to create value (Håkansson, 1987; Håkansson, Ford, Gadde, Snehota, & Waluszewski, 2009; Håkansson & Snehota, 1989, 1995).

2.2 Approaches to and perspectives on innovation and resources

It is of interest to dig deeper into the concepts of innovation and resources as they play a key role in technological development. With the organisation as the unit of analysis, innovation was defined early on by Schumpeter (2000 {1934}) as the result of new combinations carried out by the entrepreneur. Hence, both employees and other individuals could act as entrepreneurs by carrying out new combinations between new and existing means such as materials and forces. Consequently, these new combinations could result in new products or production methods as well as new markets, new sources of supply or new ways to organise business. As Schumpeter (2000 {1934}) stressed, the difficulty lies in detaching the means from existing combinations in the 'circular flow' to allow new combinations of them. The circular flow can be referred to as the equilibrium or stationary state in which the same products are produced in the same way over time. Development or innovation is thus the result of disturbing the stationary state through combining new means.

Based on Schumpeter (2000 {1934})'s definition, an innovation can be considered either radical or incremental. Incremental innovations can be referred to as the continuous improvements of existing products and processes, whereas radical innovations are completely new products and processes (Dewar & Dutton, 1986). Depending on the type of innovation, its diffusion may look different. To clarify, going from an idea to an innovation and thus putting the idea into use is seldom a linear process in terms of going from research and development to production- and marketing-related activities within the firm but an interactive and iterative process involving many actors. Kline and Rosenberg (1986) introduced the 'chain-linked model' as an alternative to the linear model and proposed feedback loops that connect research and development with production and marketing. Hence, the focus is on identifying a market need rather than on pushing out new ideas, and thus research is not the first in a series of steps but an overall activity stretching through the whole innovation process. Consequently, the source of innovation may stem from different kinds of actors, such as suppliers or users (von Hippel, 1988), building up networks from which the firm can access knowledge and resources. As Powell, Koput, and Smith-Doerr (1996) emphasised, the network plays an important role for the innovating firm as interorganisational collaboration not only helps compensate for the lack of internal competence but also strengthens existing ones.

One way to capture innovation as an interactive process is to take the point of departure in the innovation system and thus view the innovation as an outcome of the flow of technology and information shared between several mutually dependent actors, and technological development as influenced by not only the actors and markets involved but also institutions and networks (Carlsson & Stankiewicz, 1991). One type of innovation system is the national one that takes the geographical boundaries as a starting point. Lundvall (1988) defined it as a system that includes actors, such as the producing firms, universities and the public sector, and whose activities create certain routes of industrial specialisation in the specific geographical area. Another way of characterising an innovation system is to look at the actual technology and the actors involved in a specific industrial setting. Carlsson and Stankiewicz (1991, p. 111) explained a technological system as *"a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology"*. Based on this, Johnson and Jacobsson (2001) introduced several functions or contributions of system components (the actors, intuitions and networks) to the process of developing new technology. Examples of different contributions could be the creation of new knowledge to provide recognition of the growth potential of a technology and supply resources such as capital, competence and other types of resources. However, each component may also restrict the different functions and influence the development of a new technology in a negative way. As Bergek, Hekkert, and Jacobsson (2008) emphasise, technological innovation systems (TIS) contain blocking mechanisms, and policy plays an important role in removing them by, for example, enhancing user capability and awareness, supporting experimentation and facilitating resource mobilisation in terms of new knowledge from universities.

Another way to study innovation and technological development, and which is related to the assumptions on interactivity mentioned in the last paragraph, is to take the starting point in the business relationships created between firms. The Industrial Network Approach emphasises the resource layer as a significant dimension when it comes to technological development in inter-organisational networks (Baraldi, 2003; Håkansson & Snehota, 1989). Innovation could then be defined as the result of resource combinations taking place both within and between firms in the business network. Håkansson and Waluszewski (2007) highlight three different settings in which a resource must become embedded to become an innovation. Firstly, the resource must become useful in a developing setting in which it can fit into the developing partners' processes. Hence, by, for example, collaborating with universities or making use of other R&D departments, it is possible to develop new features of the resource to fit better into a using setting. Secondly, the resource needs to be produced and thus combined with other resources belonging to producers. Thirdly, the resource needs to be useful at the users' facilities and processes. Consequently, from an industrial network approach, the process of going from an idea to an innovation is explained as an iterative process in which resources are adapted between firms in all three settings in parallel.

Resources play a significant role when studying innovation and technological development (Håkansson & Waluszewski, 2002a; Jacobsson & Johnson, 2000; Powell et al., 1996). On the one hand, resources need to be allocated to explore new ideas in terms of experimenting and looking for new opportunities. On the other, resources need to be assigned to refine and improve existing technology. As March (1991) emphasises, the returns of exploration are less certain and remote in time than exploitation, which can often be connected to certain consequences more precisely. Nonetheless, both activities are of relevance to firms, and thus keeping the balance between the two in terms of finding an optimal division of resources is of outmost importance. There are different approaches to resources when it comes to interpreting their value and what can be considered to be a resource. The resource-based view (see e.g. Peteraf, 1993; Wernerfelt, 1984) stems from the notion of the firm being more than an administrative unit and rather a collection of heterogenous resources, including physical, organisational and human, which are combined into different services or products. As Penrose (1995 {1959}, p. 86) states: *"No resources, not even entrepreneurial resources, are of much use by themselves: any effective use for them is always viewed in terms of possible combinations with other resources."* Wernerfelt (1984) stressed that these combinations of resources mostly take place within the firm or through strategic alliances between firms to sustain competitive advantages for the single firm. Hence, the value of a resource is based on how well it can be combined with others to create an even better product and thus increase the value to the customers. The level of inimitability to competitors as well as the rareness compared with competitors' resources are also of outmost importance (Barney, 1991).

The service-dominant logic literature takes another approach by highlighting 'operant resources' such as core competence and organisational processes as key. As Vargo and Lusch (2004) stress, tangible resources such as products cannot exist without intangible resources. Moreover, the value of a resource is decided together with the customer, and the services and specialised competence are a vital part of the unit of exchange. Resources have also been explained in contexts other than business such as from a psychological perspective. For example, Hobfoll (2002) stresses in his conclusion that one of the main challenges in stress-related research is the objective interpretation of subjective resources such as self-esteem and self-efficacy and whether the individual's own perception of the value of a resource is more valid than its actual value.

Coming back to the business-to-business context, and specifically the literature related to the Industrial Network Approach (INA), resource development in inter-organisational networks stems from the ideas of Penrose (1995 {1959}) of combining heterogenous resources. However, as stated by Baraldi et al. (2012), resource development in inter-organisational networks takes its starting point in the interacting network rather than the independent single firm. Thus, resource combinations across firm boundaries generate different values for different actors in the network, in contrast with internal combinations, which are a driver of competitive advantage for the single firm. Consequently, resources are not exclusively controlled by a firm, but firms are interdependent and unlikely to fully control the interactions in the business network and the outcome of them. Consequently, by taking the starting point in inter-organisational resource development, an element (tangible or intangible) is considered a resource when it has a *known use* in relation to other elements, and the value of a resource is dependent on how it is used, both within the resource collection of a firm and *across* firm boundaries (Håkansson & Snehota, 1995). Hence, the value of a resource is determined by how it is used and combined with other resources and thus how the interfaces between resources develop.

Building on Alchian and Demsetz (1972, p. 792) notion of resource heterogeneity, it is important to know the different dimensions of how resources can be used in order to combine them more effectively. An example is the leasing of a hammer when *"the abuse [of the hammer] is easier to detect by observing the way it is used than by observing only the hammer after its use, or by measuring the output scored from a hammer by a labourer."* Hence, one conclusion that Alchian and Demsetz (1972) drew from the study was that the expectations of abusing the hammer were higher when only observing the hammer after its use. In order to charge the correct price for leasing the hammer (including its depreciation), it was therefore relevant to observe how the features of the hammer interoperated with the user's processes. This led to the assumption that efficient production, including heterogenous resources, is an outcome of not having more superior resources but *knowing* more precisely how they work together with other resources. While Penrose (1995 {1959}) and Alchian and Demsetz (1972) mainly talk about resource heterogeneity within the firm, INA builds upon the view of resource heterogeneity as very much related to the diverse ways in which the features of a resource are developed and used in different resource combinations across the network (Holmen, 2001; Håkansson & Snehota, 1995).

This thesis takes its starting point in the business relationships and sees innovation as a result of resource combinations taking place in the business network. Consequently, the following sections will describe resource development from an INA perspective with the emphasis on the interactive process of creating value through combining resources.

2.3 Resource development through interaction in business networks

According to INA, interaction between actors and between resources in the business network plays an important role when developing resources. It is in the interaction that different properties of the resources are visible and thus affect how they can be combined. Hence, a resource combination can be explained as the combination of two or more resources and the interaction taking place between them (Holmen, 2001). Relating the resource layer to Håkansson and Snehota (1995)'s three functions of the network, a resource is part of building up the resource collection of a firm. The resource collections are tied together through resource ties and thus form the resource constellation of the network. Holmen (2001, p. 140) refers to resource ties as *"blurry border zones between firms [...] [that] comprise all the resources as well as relations between resources, which are specific for the two counterparts."*

By combining resources, new knowledge of how to use a resource can be gained. According to Gadde et al. (2010), there are three types of resource combining. Firstly, new resources can be combined with existing ones. Adding a new resource into an existing resource structure is difficult because the existing resource structure has often been developed over many years and in relation to other resources, both within the resource collection and across the resource constellation. Letting a new resource in involves adapting not only the two resources in interaction but also those that are directly and indirectly connected to the two resources to make the resource fit into the network. Secondly, internal resources can be combined with external ones across firm boundaries to gain a new type of resource that cannot be developed internally. The external resources can be critical to success when it comes to, for example, small firms that lack important resources (Ciabuschi, Perna, & Snehota, 2012). The third aspect is connected to the 'double-faced nature' of the resource and concerns the matching of supply and use. As pointed out by Håkansson and Waluszewski (2002a), every resource has a produce side since it is developed and manufactured by a supplier and a use side where it is used in a context of other connected resources. Connecting the two sides can be difficult since what can be perceived as efficient and effective on the produce side is not always perceived the same on the use side. Therefore, and as also pointed out by Håkansson and Snehota (1995), a resource can be viewed as a relation between the supply and usage of resource elements.

To explain how a resource can be used in other firms' resource collections, Holmen (2001) introduced the concept of resource versatility. Versatility can be realised by either combining a resource with another, which in turn results in a completely new resource that fits better with the existing resource constellation, or through modifications, i.e. changing the features of the resource to achieve a better fit. From an INA perspective, a resource has what can be called 'bounded infinite versatility', which means that a resource can be combined in an infinite number of ways since the number of resources it can be combined with is endless. However, since each resource has specific features it will not be useful in an unlimited number of resource combinations but limited to the number of ways the features can be adapted. That said, a resource always has unknown characteristics, as there are always new ways to combine it with present or novel resources (Baraldi et al., 2012; Håkansson & Waluszewski, 2002a; Lind, 2006). Additionally, Holmen (2001) takes it one step further by discussing the importance of *potential use* and value. From an INA perspective, a resource is an element with known use in relation to other resources and thus has a certain value. However, Holmen (2001, p. 141) asks the question of whether *"it might be advantageous to define resources also in relation to potential use and value instead of only in relation to known use and value".* If so, the main criterion for evaluating whether an element can be regarded as a resource would stem from the expectations of finding a new use for an element and not only from the already known use. Moreover, resources can have unexplored use potential in addition to their existing use value, and thus these resources (and elements) should also be considered part of the resource collection of a firm. Holmen (2001) also points out that each resource has a memory of all the different combinations in which it has been tried out and thus explored. In this case, a degree of explored versatility can be considered in terms of the number of combinations in which it has been tried out.

The versatility of a resource is of outmost importance when considering technological development in business networks. Combining resources across firm boundaries and confronting and adapting them to make them useful in other firms' resource collections is an important activity when developing new technology (see e.g. Baraldi, 2003; Håkansson & Waluszewski, 2002a; Laage-Hellman, 1989; von Corswant, 2005). Thus, technological development can be seen as a result of a number of actors' interaction processes in the business network, including potential users, manufacturers and third parties such as universities and research institutions (Biemans, 1992). Moreover, the innovating firm's resources must become embedded in different business network settings that include actors which facilitate the various stages of turning the resource into a product. For example, there are producers that make the product in their production facilities, users who use the product in their processes and developing partners whose laboratories are used to develop resources to fit into the users' and producers' processes (Håkansson & Waluszewski, 2007). Making a resource useful in the three settings of developing, producing and using is not a straightforward but a parallel process in which the focus is on matching the supply and usage side of the resource with regard to the counterparts' resource collections. Consequently, it is important to achieve proximity between the three settings (Baraldi, Gregori, & Perna, 2011; Landqvist & Lind, 2019) as the greater the difference between them, the harder it is to embed a new resource in the business network (Ingemansson & Waluszewski, 2009).

2.3.1 Organisational and technical resources and their interfaces

The process of developing new technology through combining resources in interaction is complex and often includes an ambition to create both stability and change in the interfaces between the resources. As defined by Prenkert et al. (2019, p. 14), a resource interface is *"the contact points along a shared boundary between at least two specific resources. These contact points influence the technical, economic and social characteristics of the involved resources."* Hence, the interface is not a result of two interacting resources but the contact point at which two resources interact. In time, the interface develops, and the way it does this depends on how the features of the resources can be adapted to each other (Baraldi, 2003; Gadde & Håkansson, 1993). On the one hand, stability in an interface is necessary to ensure efficient use of the resources in the combination and that the features of the resources are adapted to work well together. On the other, there must be room for change in the interface so that better combinations or adaptations can be achieved if necessary.

Håkansson and Waluszewski (2002a) identified four types of resource categories belonging to either technical or organisational forms that are central when carrying out technological development in business networks. These four categories are products, facilities, organisational units and relationships. As concluded by Gressetvold (2004), these four resource types are interrelated, i.e. the technical and organisational resources are combined in one way or another. By combining the resources with each other, both internally and across firm boundaries, they are all subject to change. The four categories of resources can be summarised in the 4R model. As Baraldi et al. (2012) emphasise in their conclusions, the 4R model can be seen as a fine-grained tool for mapping and analysing resources and connected interaction processes in inter-organisational innovation processes. Thus, the resource interfaces between organisational and technical resources play a key role when creating new technical solutions and embedding them in the business network. Baraldi et al. (2011, p. 839) explain that: *"We define this creation of interfaces between the tangible and intangible resources that influence a new technology's transformation into an innovation as the embedding of that solution."* The embeddedness of a solution is related to the level of heterogeneity of the focal resource, specifically, the more 'shapes' it can assume, the easier it will be to embed in a developing, a producing and a using setting.

The group of technical resources includes the two resource categories of products and facilities. The *products* can be single items or a system comprising not only the item itself but also additional services. From an inter-organisational perspective, it is rare that a product is given, as its features are changed in the interaction between the firms (Håkansson & Waluszewski, 2002a). Moreover, there are *facilities*, such as buildings, research labs, production facilities, infrastructure, handling equipment and vehicles. By connecting resources belonging to different facilities, companies can adapt production and handling of the product and thus save both time and money (Håkansson & Waluszewski, 2002a). The group of organisational resources includes business units and business relationships. The *business unit* in turn includes social resources, such as internal knowledge and competences as well as knowledge about the corresponding company and an understanding of how to work with it. Moreover, it contains organisational routines and organisational structures. Furthermore, the *business relationship* is strongly connected to time and past interaction and future plans between firms. Gadde, Hjelmgren, and Skarp (2012) emphasise the importance of making use of the business relationship as a resource since it enables access and use of physical resources outside the firm boundary. It can be seen as an asset, as it is used in a number of value-added processes, such as contributing to innovation and improving operational efficiency (Jahre, Gadde, Håkansson, Harrison, & Persson, 2006).

With regard to the previously mentioned resource categories, three types of resource interfaces can be identified. Firstly, Dubois and Araujo (2006) categorise two types of resource interfaces: *technical* and *organisational*, which become visible when two technical or two organisational resources interact with each other. Secondly, Jahre et al. (2006) point out the *mixed* interface, which results from a combination of one organisational and one technical resource. Jahre et al. (2006) claim that the mixed interface is more complex than those occurring between two technical or two organisational resources. One reason for this is the economic characteristic connected to the organisational resources. However, it is also in these interfaces that value is generated by embedding the technical resources in organisational structures. This is as a dynamic process in which there is a need to constantly let resources interact with each other to improve the fit between them.

In the context of technological development and combining new resources with existing ones, it is also important to consider the interplay between the ideas related to new combinations and the existing resource structure. As Håkansson and Waluszewski (2002a) point out it is important to understand how much advantage an idea can gain from current solutions as well as how much the existing resource structure is reflected on in the idea. The idea structure is never stable but contains different logics and visions of the actors as well as knowledge of different technical opportunities and actors' problems that develop over time and in relation to the business network. Actors may organise their resource collection in support of a new idea or already be able to take advantage of the 'activated resource structure' within the firm. Consequently, there is continuous adaptation between the ideas and the 'activated resource structure' in terms of, on the one hand, how an idea can take advantage of, or build on, an existing solution and thus be part of the existing resource structure and, on the other, how the idea structure can change in order to make existing resources fit into it.

2.3.2 Resource interfaces and their connections in business networks

Taking the view of technological development as a result of resource combinations, it can be said that it is not a result of the activities carried out by only two firms in the dyad but of several supporting relationships in the network. According to Baraldi and Strömsten (2006), the value of a resource when combined with others to achieve a new useful resource is easiest to recognise when observing several direct and indirect resource interfaces across the entire network. By taking the perspective of the resource constellation and studying how connected interfaces impact each other, it becomes clear that the value of a resource does not necessarily depend only on the resource's internal features but also on the way the interfaces develop between directly and indirectly connected resources. The resources can be seen as pieces of a puzzle that have initially not been shaped to fit the common puzzle (Gadde & Håkansson, 1993). Thus, the interfaces between them may not fit, and the resources may need to be adapted to each other.

From an inter-organisational perspective, it is supposed that a single resource can be involved in several internal and external ties at the same time (Håkansson & Snehota, 1995). This notion of taking advantage of a single resource in different ties simultaneously is not acknowledged to the same extent in other theories. The Transaction Cost Theory and Riordan and Williamson (1985)'s previous work on *asset specificity*, which is related by some means to the INA concept of *resource ties*, primarily take the starting point as the single relationship between two firms, specifically those business situations that result in the development of a relationship between two firms with the aim of governing transactions between them. The higher the degree of asset specificity in the relationship, the less the asset can be used in other relationships. These asset specificities are linked to the following categories: site specificity, such as resources available in a certain place; physical asset specificity, which is linked to, for example, specialised tools; and human asset specificity, including specialised human skills and dedicated assets such as investments in plants that are dedicated to one specific purpose. In this situation, it becomes difficult to change partners, as the firm is 'tied in' to a relationship due to the large investments in the relationship and the specific use of that asset in the specific relationship. To clarify, on the one hand, there are asset-unspecific investments, in which equal returns across a diversity of settings can be expected. On the other, there are asset-specific investments which will give a large return for the specific purpose used but not elsewhere.

Looking at this from an INA perspective, Håkansson and Snehota (1995, p. 379) and Holmen (2001) stress that there may be situations in which the asset specificity is not high but still creates special connections between relationships that are as strong as those between individual firms. Consequently, instead of talking about being 'tied in' to a specific relationship, there may be substructures in the network in which several relationships are 'tied in' to each other. This is also relevant in the resource dimension. Dubois and Araujo (2006)'s study on supplier involvement in developing a new lorry model revealed that one specific resource feature could actually impact three levels of the substructure: (1) the individual component (or resource), (2) the interface between the component and the other resource, and (3) the connected interfaces. Thus, solving one problem in one specific resource interface by adapting the features of the resources involved in the tie may have an impact on other connected interfaces both within the firm and across the network.

Moreover, Håkansson and Waluszewski (2002a) describe the concept of *friction* as a way to explain how the adaptation or development of features in one specific interface may influence the connected interfaces. Hence, friction is the resulting reaction when pointing a force towards a specific resource that already interacts with other resources. The following effects of friction were identified: (i) it distributes the reaction to all resources that have interfaces with the focal resource, (ii) this in turn creates tensions in the interfaces between these resources and (iii) it affects the resources differently given the specific point in time. Namely, friction is necessary to transform interfaces to enable a better fit between the interacting resources. It is through friction that new resource features can be established, resulting in new solutions. When technical and organisational resources interact, their specific features will trigger changes in other connected interfaces. For example, a trigger in a mixed interface may trigger a change in a technical interface. Landqvist (2017) exemplifies this in a start-up context through the study of combining a smart medicine package with its users' routines at a retirement home. A lack of previous experience among the users of the mixed interface between the technical resource (the smart package) and the organisational resource (knowledge at the retirement home) triggered a change in the technical interface between the GSM module and the package. Thus, adaptations had to be made to facilitate the integrations of the GSM module and the package to make the smart package useful for the elderly people.

However, changing a specific interface is not always easy. In the discussion on being tied into a relationship (Riordan & Williamson, 1985) and substructures in the network (Holmen, 2001; Håkansson & Snehota, 1995), it became clear that the more investments and adaptations that are made to a specific resource tie, the harder it is to disconnect or change it. Håkansson and Waluszewski (2002a) call this *heaviness*, referring to the difficulty of disconnecting or recombining already combined resources. Håkansson and Waluszewski (2018) identify three dimensions to estimate the degree of heaviness. Firstly, heaviness refers to the degree to which two actors have made technological and organisational adaptations between each other. Secondly, it refers to the amount of time the two actors have spent establishing and preserving the relationship. Thirdly, it refers to the set of relationships to which the exchange situation is connected in terms of other actors, resources and activities. In addition, the more central the resource combination is to the resource constellation, the heavier it becomes. In the technological development processes in the business network, heaviness indicates that certain trajectories may be less attractive due to the costs that adaptations and new combinations may require to develop new technology. Håkansson and Waluszewski (2018) also emphasise the differences in which heaviness is recognised in the three settings of developing, producing and using. Hence, it is known that many ideas are difficult to embed in a producing and a using setting due to their heaviness and, consequently, the heaviness destroys many of them, or, at least, the ideas develop in a direction that is beneficial to the existing heavy resource structure. As showed by Håkansson and Waluszewski (2002b), heaviness can occur in, for example, industrial areas in which many interfaces have been created between physical products with high economic value, such as, for example, the paper and pulp industry.

Håkansson and Waluszewski (2002a, p. 192) give the following example of how interaction between resources can affect the resource category of facilities, on the one hand, by developing unique features that result in heaviness and, on the other, by making the facility less important in relation to other resources: *"through interaction processes between different resources that are adapted in relation to each other, some unique features of the facility are developed. These unique features are only activated in relation to some other specific features […] consequently, in relation to resources where no special features are developed and utilized, the facility can easily be compared with and replaced by others."* Thus, the resources in the business network allow for a huge number of combinations and new interfaces. This is a result of the *variety* of resources, namely how distinctive they are in relation to others and how they are combined (Håkansson & Waluszewski, 2002a). Connecting friction to the variety dimension implies that friction in one interface can affect other interfaces of the focal resource and hence create even more variety of resources. The concepts of *heaviness* and *variety* are thus important to understanding how firms can develop and manage their resources (Baraldi et al., 2012).

2.4 Analytical framework: embedding resources in resource structures

When embedding new technology in the business network, i.e. resources in a resource structure to make them useful, the new resource interfaces between the new resources and the existing ones may trigger changes in other connected resource interfaces. According to Baraldi et al. (2011), *embedding* is defined as the creation of interfaces between resources that impact the development of an innovation. It is a trial and error process in which the interfaces are developed in interaction, and a new interface can trigger changes in connected interfaces and existing interfaces can trigger changes in the new interface. Hence, the technical and organisational resources combined to develop, produce and use the new resource will result in a number of different resource interfaces whose resource features may be subject to change (Håkansson & Waluszewski, 2002a). There are three types of resource interfaces that can become visible: the technical and organisational interfaces between two technical and two organisational resources (Dubois & Araujo, 2006) and mixed interfaces between one technical and one organisational resource (Jahre et al., 2006).

In the study, the key resource concepts are defined as follows. A resource combination is a combination of two or more resources that interact. A resource interface is the contact points along a shared boundary between *two* specific resources that interact and influence the technical, economic and social characteristics of the involved resources. Figure 1 shows a focal resource and its three resource interfaces in the context of what Håkansson and Snehota (1995) refer to as the three functions of the business relationships: the *resource collection* of the firm such as the resource collection interface ($RI_{R1\text{-}R4}$). The *resource tie* between two firms such as the resource tie interface ($RI_{R1\text{-}R2}$). A resource tie is the border zone between firms that comprises all the resources and relations between resources specific to the two counterparts. Moreover, the *resource constellation* built up by several firms in the business network. The figure shows a state in which the focal resource is embedded in the resource constellation. However, to reach this state not only are new interfaces created but some are disconnected and some develop new features to enable the new resource to become useful. The heterogeneity of the resources is illustrated by the different shapes in the figure. Taking the starting point in one specific resource interface, it can either belong to a resource collection of an actor or a resource tie between two actors.

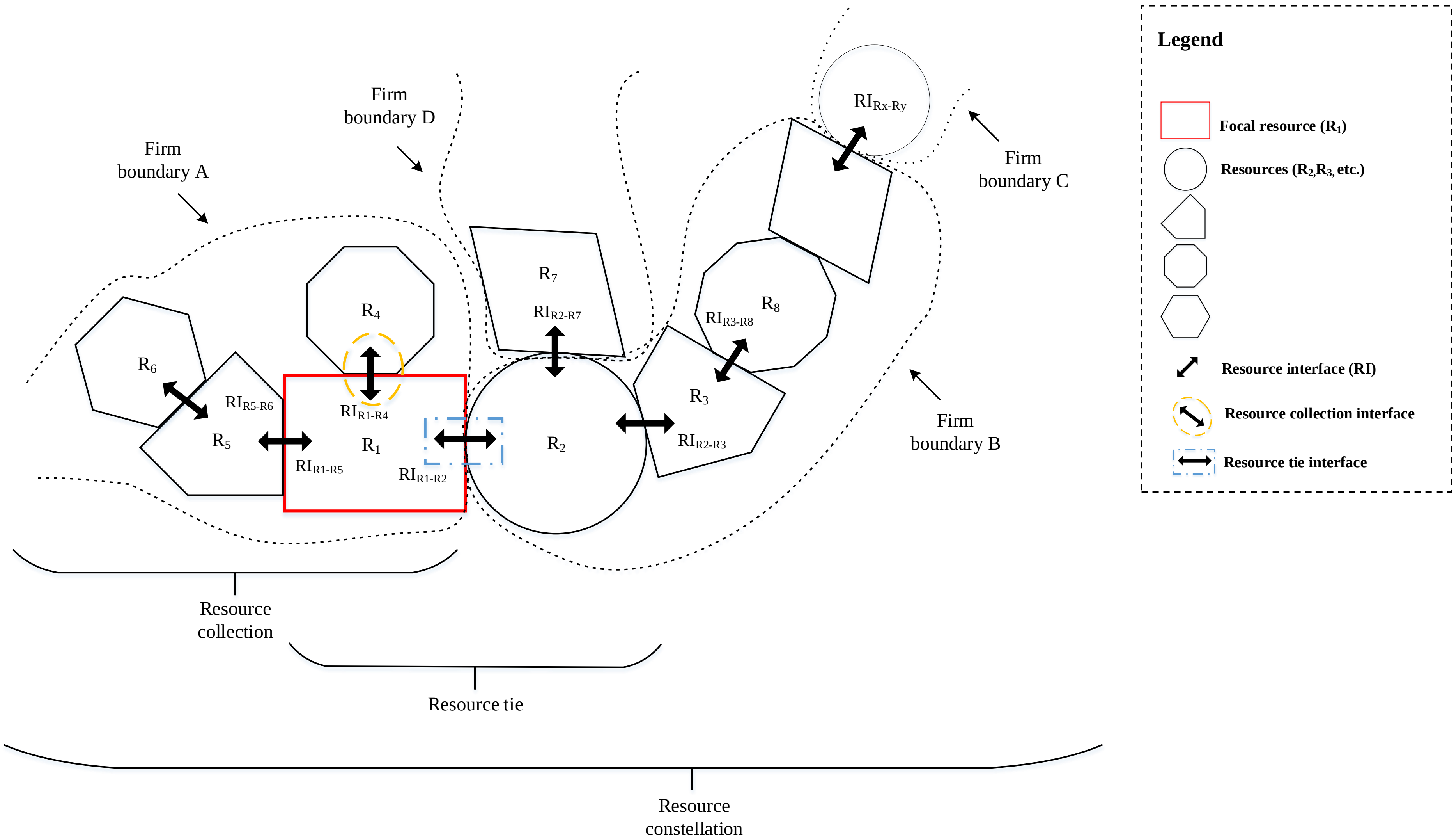

Figure 1. Resource interfaces within a resource collection, a resource tie and a resource constellation

Figure 1 above shows several types of connected resource interfaces that result from triggers and changes taking place between resource interfaces. Moreover, when taking the starting point in an interface that belongs to what Håkansson and Snehota (1995) refer to as either a resource collection of an actor or a resource tie between two actors, eight categories of connected resource interfaces, including the three types of organisational, technical and mixed, can be identified. The following categories of connected resource interfaces can be seen:

(1) A *resource collection* interface (RI_{R1-R4}) within a resource collection of a firm may trigger a change in
   - a. a *directly* connected resource interface either
     - (i). within the resource collection of the firm (RI_{R1-R5})
     - (ii). or in a resource tie (RI_{R1-R2}).
   - b. an *indirectly* connected resource interface, with at least one interface between, either
     - (iii). within the resource collection of the firm (RI_{R5-R6})
     - (iv). or in a resource tie (RI_{R2-R7}).

(2) A *resource tie* interface (RI_{R1-R2}) may trigger a change in
   - a. a *directly* connected interface either
     - (v). within the resource collection of a firm (RI_{R2-R3})
     - (vi). or in another resource tie (RI_{R2-R7})
   - b. an *indirectly* connected interface, with at least one interface between, either
     - (vii). within the resource collection of a firm (RI_{R3-R8})
     - (viii). or in another resource tie (RI_{RX-RY}).

Based on this, an analytical model of connected resource interfaces in business networks is created, as seen in Figure 2.

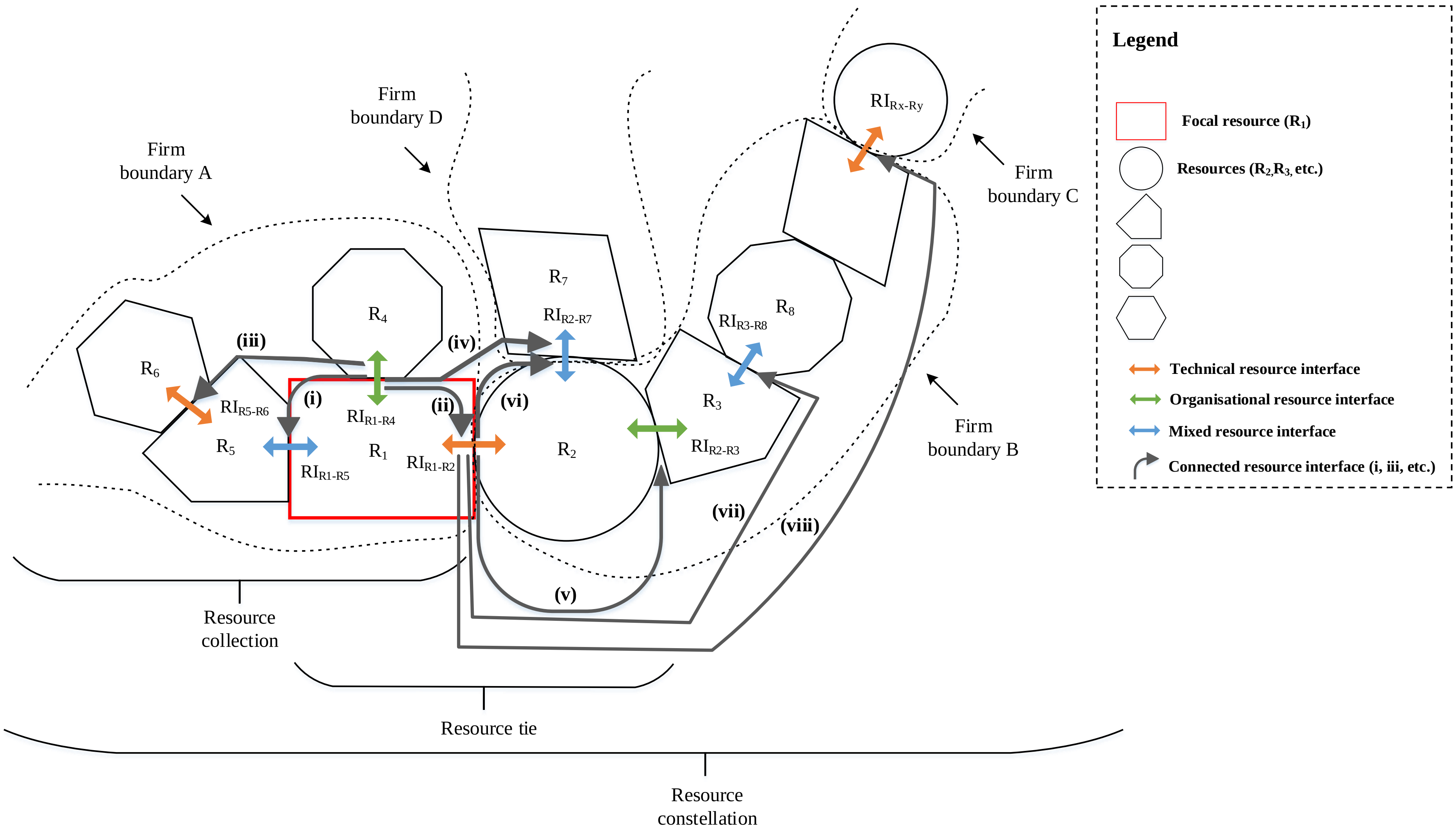

Figure 2. An analytical model of connected resource interfaces in business networks

To capture different patterns of resource interaction necessary to embed a resource into a resource structure, it is essential to start on a micro level in the various types of connected resource interfaces created. Hence, the first research question will explore how resource interfaces are connected to each other when embedding a new resource in a resource constellation:

- **RQ1. How are resource interaction patterns related to connected resource interfaces?**

Table 1 is based on the analytical model in Figure 2 and used as a template to capture the various types of connected interfaces related to different resource interaction patterns in a structural way. Hence, the analysis takes its starting point in a resource interface, either within a resource collection of a firm or in a resource tie, as illustrated in the rows of the table. The resource interface can be technical, organisational or mixed and trigger a change in several connected interfaces in the business network, as illustrated in the columns of the table.

Starting from a resource collection interface, a change can be triggered in four ways: Firstly, in a directly connected interface within the resource collection of the firm, being either a technical, organisational or a mixed one (i). Secondly, in a directly connected interface in the resource tie between two firms, also being either a technical, organisation or a mixed one (ii). Thirdly, it can trigger a change in an indirectly connected interface, with at least one interface between, in a resource collection (iii) or in the resource tie between two firms (iv). Here too, the connected interfaces can be either technical, organisational or mixed ones.

Starting from a resource tie interface, a change can also be triggered in four ways; in a directly connected interface within the resource collection of the firm (v), in a directly connected interface in the resource tie between two firms (vi), in an indirectly connected interface with at least one interface between, within a resource collection of a firm (vii) or in the resource tie between two firms (vii). Likewise, these connected interfaces can be either technical, organisational or mixed. The eight categories of connected interfaces are shown in Table 1.

Table 1. A template for capturing various types of connected interfaces in the business network

		Directly connected resource collection interface			**Directly connected resource tie interface**			**Indirectly connected interface (at least one interface between)**					
								A resource collection interface			**A resource tie interface**		
		Org.	Tech.	Mix.	Org.	Tech.	Mix.	Org.	Tech.	Mix.	Org.	Tech.	Mix.
A resource collection interface	Org.	(i)			(ii)			(iii)			(iv)		
	Tech.												
	Mix.												
A resource tie interface	Org.	(v)			(vi)			(vii)			(viii)		
	Tech.												
	Mix.												

Furthermore, as explained by Holmen (2001), a resource can be combined in an endless number of ways but only be useful in a specific number of ways due to its features. To realise the potential versatility of a resource in a resource constellation, a resource can be combined with other resources to create a new useful resource or be modified by changing its features. However, it is not only in the specific resource interface that it is determined whether the potential versatility of a resource can be realised: the connected resource interfaces also play an important role. Hence, in order to embed a resource in a resource constellation it is important to understand how the existing resource constellation can both restrict and enable the versatility of the resource. Consequently, after identifying the different resource interaction patterns visible when trying to embed a resource into a resource constellation, it is of interest to study how versatility relates to the connected resource interfaces and the associated resource interaction patterns, i.e. how the versatility of the resource is explored in interaction. The second research question therefore looks at the implications for the versatility of a resource of embedding it in a resource constellation:

- **RQ2. How is the versatility of a resource explored in a resource constellation?**

After identifying the resource interaction patterns and how they relate to connected resource interfaces, and the versatility of a resource has been explored in interaction in the resource constellation, it is of interest to study the effects of the resource interaction patterns on particular resource constellations (i.e. resource constellations related to the Swedish energy system). By analysing the resource interaction patterns in relation to three resource constellations, it is possible to analyse how the potential versatility of a resource can be realised in the three resource constellations. This leads to the third research question:

- **RQ3. What are the effects of the resource interaction patterns on the resource constellation?**

3. Method

This chapter discusses the method used in the study. It starts in the research context and the environment in which the study was conducted. The methodological choice of conducting a case study is then discussed together with the research process and data collection. The chapter ends with a reflection on the choices made throughout the research process.

3.1 The research context

The study takes its starting point in a project called *University entrepreneurship: The case of university spin-offs in a network perspective (USONET).* The project, which included researchers from Lund University, Örebro University and Chalmers University of Technology, started in January 2015 with the aim of contributing new knowledge on the complex process of commercialising science. This was done by analysing spin-offs in a network perspective in terms of how they interact in business networks to commercialise their ideas and study the effects of the interaction on the innovation, the spin-off itself and the network. A licentiate thesis was published as part of the USONET project on how start-ups *relate* to different components in the network, such as other firms and resources, in order to innovate. From a theoretical point of view, the study took its starting point in the Industrial Network Approach (INA) to industrial markets, emphasising interaction and interdependencies between firms. As the initial aim was to study the interaction between firms and thus use the business relationship as a unit of analysis, it was understood that INA could provide a suitable toolbox in terms of capturing the technological development in the interaction taking place between the firms, including start-ups and established firms in the business network.

When the first project ended in 2017, it resulted in the licentiate thesis. The thesis developed my interest in renewable energy technologies and the journeys of the start-ups related to the Swedish energy system. Consequently, based on the two case studies of Swedish Algae Factory's and Aqua Robur's technological development processes, a new project called *Technology-based start-ups as engines for renewable energy* was financed by the Swedish Energy Agency to continue following the two start-ups' journeys. This project began in 2017 and aimed to create a better understanding of how start-up companies establish in network structures and function as engines for renewable energy technology, thus resulting in this doctoral thesis. Consequently, parts of this method chapter relate to the part of the study reported in the licentiate thesis (Landqvist, 2017), as it is the basis for this doctoral thesis.

Being a PhD student at the former division of Industrial Marketing at Chalmers University of Technology, which has since been merged into the new division of Supply and Operations Management, provided me with a foundation of knowledge on which to approach the research project. The research group takes its theoretical starting point in the Industrial Network Approach, and by taking part in research seminars on a regular basis as well as PhD student seminars, which are held every six months in the division, much valuable input was gained during the process of conducting the study and writing this doctoral thesis. Several IMP conferences and other related workshops were also attended, for example the Nordic Workshop on inter-organisational research, to broaden my knowledge within the field of research. Furthermore, there was an opportunity within the frame of the first project to participate in writing a book chapter on the topic of starting up in business networks (Laage-Hellman, Landqvist, & Lind, 2017). Two journal papers were also published: one focused on how technology-based start-ups collaborate with customers in product development (Laage-Hellman, Landqvist, & Lind, 2018) and the other dealt with networking behaviours of start-ups and looked in more detail at how the interplay between strong and weak ties facilitates the embedding of the start-ups' resources in the three business network settings (Landqvist & Lind, 2019). While the second project started to take shape, two conference papers with a new focus on starting up in the Swedish energy system were presented at the IMP conferences. The first paper concentrated on gathering the preliminary thoughts on how to analyse the Swedish energy system as a 'heavy' resource structure and the implications it had on the embedding of a new resource (Landqvist, Dubois, & Lind, 2018). The second paper dealt with a parallel focus and, specifically, how to create a local energy system in the south of Sweden and how the business relationship between the Swedish energy company E.ON and the Italian company Loccioni acted as an enabler for renewable technology (Landqvist, Lind, Perna, & Palermi, 2019). Thus, the context from which this doctoral thesis originates is built on three pillars: (1) the interest in the commercialisation activities of start-ups, (2) the need to transform the Swedish energy system to become 100% renewable and (3) the call to develop analytical tools to understand the implications of bringing a new resource into the business network.

3.2 A case study approach to capture resource interaction in business networks

As this thesis deals with resource interaction in business networks, an in-depth analysis of each specific start-up and its relationships with the surrounding actors was required to explore the effects of the interaction on the start-up's resources and network over time. This is in line with Bryman and Bell (2015), who argue that in order to understand why someone acts in a specific way, the context must be understood and seen through the eyes of the people being studied. This required an understanding of the context in which the start-ups operate, which called for a qualitative research approach.

When considering which type of research design would be suitable for this qualitative study, case study research, a well-known and frequently used research method for studying organisations in networks, was chosen as it is well suited to studying technological development in business networks (see e.g. Easton, 2010; Piekkari, Plakoyiannaki, & Welch, 2010). As Dyer and Wilkins (1991) stress: *"the emphasis of the classic case study approach is to highlight a construct by showing its operation in an ongoing social context."* Hence, a case study should act as a story and not only as statements of constructs. The clarity of the constructs originates instead from the story by explaining deeper social behaviours and dynamics. Using a *single* case study can enable more detailed study and thus allow new theoretical relationships to be explored (Dyer & Wilkins, 1991). This study aims for analytical generalisation in terms of developing concepts to be used also in other contexts. Easton (2010) suggests that deeper and broader explanations are required when aiming for theory development. Hence, in this study a single case of 'Starting up in the Swedish energy system' was developed by describing the development of the Swedish energy system and its current transformation as well as the technological development processes of three start-ups that want to be part of the transformation. This study used an embedded single case design (Yin, 2013) in which the purpose was not to aim for statistical representativeness but to add variation to the empirical evidence and build an understanding of the phenomenon studied, in this case resource interaction in business networks.

To use a metaphor: the phenomenon is a circle composed of different parts (or cases), and each provides its own specific explanation of the mechanisms and processes underlying an event that is about to happen. Hence, the deeper explanations of specific events (or cases) can together provide a broader explanation of the phenomenon as such. Building context-specific subcases of how each unique start-up creates relationships with external actors enabled an understanding of the underlying reasons and motivations for each relationship as well as how the business network functioned. This is in line with Halinen and Törnroos (2005) who argue that a case strategy for studying networks is necessary as the separate unit (such as the relationship) is heavily dependent on its context. Furthermore, to understand how the start-ups related to the Swedish energy system, it was necessary to embed each of the three subcases into the single case of 'Starting up in the Swedish energy system'. When doing so, it was possible to capture the less obvious aspects or motivations for why the technological development process for a start-up in this context may or may not work.

3.3 A systematic combining approach

The research process of the study has been characterised by an abductive approach and, in particular when talking about single case studies, a systematic combining approach (Dubois & Gadde, 2002). To clarify, the case and the theoretical framework have continued to evolve while going back and forth between the theory and the empirical world. Thus, the case has been a tool to interact with both the theory and the empirical world to understand which new parts can add to the analysis and in the end also a product or, better still, a story of its own. Hence, it is important to recognise that during this research process there were never any final products as there was continuous development of the case and the theoretical framework. The following paragraphs will provide an insight into the main directions and redirections.

The *overall direction* of the study deals with the starting up processes in the Swedish energy system and, in particular, resource development in interaction. In the study, the start-ups were the study objects that wanted to enter the energy system with new technology. Due to their early stages of development and limited number of business relationships, they allowed the initial business relationships that were created to commercialise ideas in new business contexts to be captured. Later, this also facilitated the process of capturing the involved resources interacting in the business network to enable new resources to take shape.

The overall direction of the study required some initial redirections in the theoretical framework, which were made during the first study between 2015 and 2017. By taking the theoretical starting point in the Industrial Network Approach and specifically in the ARA model (see e.g. Håkansson & Snehota, 1995), I learnt that business relationships contain activities, resources and actors. Through exploring the literature, I also came across the three business network settings of developing, producing and using (Håkansson & Waluszewski, 2007; Ingemansson, 2010), which provided a way of understanding how innovation takes place in business networks in the form of resource interaction. In my mind, I perceived that start-ups make efforts to reach out with their ideas to commercialise them, hence creating an innovation. This is done by trying to establish business relationships with other actors. Based on this initial notion, the first aim became to study the interaction between the start-ups and other firms and thus use the business relationship as a unit of analysis. When relationships are established in all three settings, the start-ups may be perceived as established in the network as the idea has been developed, produced and finally used, a process that it was assumed would not occur sequentially but in parallel in all three settings. Consequently, the first interview guides were constructed around the three business network settings together with the ARA model (Landqvist, 2017).

When starting the case analysis during the transcription of the interviews and later the coding of them according to the ARA model and the three business network settings, it was possible to begin identifying the specific relationships and their locations in the three settings. However, the data revealed a strong connection to the actual resources and the importance of embedding them (or the products) in existing resource structures. This led to the 4R model (Håkansson & Waluszewski, 2002a) being considered and a focus on the process of combining resources in the three settings. Hence, the second part of the overall direction was refocused on 'resource development in interaction'. As a result, the forthcoming interviews were more precisely focused on resource combinations by letting the interviewees talk in detail, and in their own words, about how their resources were combined with other actors' facilities, business units and business relationships. Furthermore, to better capture the start-ups' journeys, the data collection was extended to include additional data sources such as newsletters, homepages and learning journals.

Coming back to the case analysis, it could be seen that it would be difficult to talk about products as part of the 4R model, since the algae and the turbine were under continuous development and hence not market ready. As Håkansson and Waluszewski (2002a) point out, there is a difficulty in treating an industrial product as given since its features are developed through the interaction between the buyer and seller. In this case, the empirical world revealed the start-ups' greater focus on adapting their solutions together with developing partners, potential users and producers, than selling an existing product. It was evident that the solutions had characteristics that were not always in line with what their counterparts wanted. To understand this theoretically, a move away from the 4R model was made and replaced with a focus on the particular resource interfaces and features developed between technical and organisational resources (Dubois & Araujo, 2006; Gadde & Håkansson, 1993; Jahre et al., 2006) and the concept of friction (Håkansson & Waluszewski, 2002a), i.e. how a 'trigger' in one resource interface brings about 'change' in *connected resource interfaces*. In this case, these reactions were the results of the start-ups' attempts to embed their resources in existing resource collections and hence develop valuable products. At this stage, an analytical model of connected resource interfaces that could help in analysing the process of embedding a resource in a resource structure was starting to take shape, capturing the impact on not only directly connected resource interfaces but also those located further away in the network. By including the concept of network functions: resource collection, resource tie and resource constellation (Håkansson & Snehota, 1995), it was possible to capture the resource interfaces that were located further away in the network, and by combining them with the concepts of resource interfaces, it was possible to address different types of connected resource interfaces. Furthermore, this could help to explain different *resource interaction patterns* that may occur when a resource becomes embedded in resource constellations.

When developing the case descriptions, it could be seen that the logic and visions of both the start-ups and other actors in the business network were often in conflict and that it was important for them to learn and adapt by understanding how the focal resource could match their counterparts' visions. It was not clear how vision and logic could be integrated as organisational resources and therefore it was assumed that they were treated as part of the organisational structure. Hence, building on the first part of the research process, the first research question was set: RQ1. How are resource interaction patterns related to connected resource interfaces?

The analysis of the connected resource interfaces in each of the three resource constellations resulted in a table of various types of connected resource interfaces. From this table it was possible to see patterns of directly and indirectly connected resource interfaces. The purpose of identifying these patterns was to start addressing resources as part of the development of the wider network. What would the effect on the network be if a new resource entered? All three resource constellations belonging to the start-ups' technological development processes were valuable in order to identify these patterns. Some patterns were clearly seen in all three resource constellations, including the three types of resource interfaces (technical, organisational and mixed), and some were a result of different connections between resource interfaces adding up to a particular pattern.

Patterns (1), 'the technical resource tie interface and its effect on a directly connected resource collection interface' was identified in three out of four resource constellations, and (2), 'the interplay between resource interfaces and its effects on a directly connected resource tie interface', were identified in all four resource constellations. Thus, they are regarded as important resource interaction patterns necessary to the process of embedding a resource in a constellation, no matter what type of innovation or resource constellation it concerns. Pattern (3), 'a resource collection interface and its effect on an indirectly connected resource collection interface', included several different types of resource collection interfaces (technical, organisational and mixed) in three out of four resource constellations, which shows the importance of considering the network effects of resource interfaces belonging to a collection. Hence, it illustrates the importance of considering how firms' internal processes affect other actors in the business network. Pattern (4), 'a technical resource tie interface and its effect on an indirectly connected resource tie interface', was also identified in examples from two of the resource constellations, and pattern (5), 'a mixed resource tie interface and its effect on an indirectly connected resource collection interface', was identified in one of the resource constellations. Both patterns (4) and (5) illustrate the effect of a resource tie interface on other resource ties in the network. However, there was a distinction between them depending on whether the starting point was taken in a technical or a mixed interface. In this case, the patterns were significant as they showed the principle of how changes between two actors' resources evolve in the network through other resource ties.

Another important notion when dealing with innovation, seen as a result of resource combinations across the business network, is the heterogeneity of the resources. As the resources were all unique, and the resource interfaces developed in unique ways, it affected how the resource interfaces connected to each other. One way to analyse the consequences of heterogeneity is through the concept of versatility and how it can be realised through either modifying or combining resources to create new useful ones (Holmen, 2001). In the beginning of the analysis, the versatility of a resource was treated as a given characteristic, as determined by its potential number of application areas. However, as the analysis progressed it was evident that a resource with a high level of versatility in one constellation may not have it in another. Taking the algae as an example, they may have had a high level of versatility in the hands of Swedish Algae Factory but not in the hands of another start-up with a different type of business network. Consequently, it was more relevant to talk about potential versatility, which could be realised through exploring and exploiting resource interfaces. Hence, a resource could be subject to a *high or low degree of exploring versatility* depending on the particular resource constellation it is about to become embedded in, rather than having a fixed level of versatility from the beginning. By using the concepts of exploring and exploiting (March, 1991), it was possible to capture the implications of versatility on the process of embedding a resource in a resource constellation, with the focus on the resource interfaces and the resource interaction patterns. Consequently, this led to the second research question: RQ2. How is the versatility of a resource explored in a resource constellation?

When it came to the subcases, they were developed together with the theoretical framework, and they started to take shape after the initial analysis of the transcriptions. Background descriptions of the start-ups were written early in the research process, but the longitudinal stories of the interactive technological development processes were an outcome of the interviews specifically related to the resource combinations. When the new project started to take shape in 2017, and the first part of the overall focus was set, 'starting up in the Swedish energy system', a redirection in the empirical world was made to capture the characteristics of the new context in which the start-ups aimed to participate. It also presented the need for a third subcase that could reflect additional aspects and variations in the process of start-ups becoming part of the energy system. Moreover, by describing the Swedish energy system from an actor perspective and highlighting the components from which it is built, it became clear that new theoretical concepts needed to be added to the framework. Hence, in the beginning of the analysis, the resource constellations of the Swedish energy system were analysed with regard to the heaviness concept (Håkansson &

Waluszewski, 2002a), which was used as a way to understand the implications of embedding a resource in a context that has been shaped for many years for a specific purpose. However, it became evident that heaviness was mostly experienced by actors in the process of entering the system rather than those already part of it. Consequently, the third resource question changed from focusing on how to realise the potential versatility of a resource in a heavy resource structure to analysing the effects of applying the resource interaction patterns to resource constellations that make up the resource structure of the Swedish energy system. As a result, a link between the micro level of resource interfaces and the macro level of the energy system was developed, facilitating a discussion on how the versatility of a resource could be realised in the Swedish energy system. This led to the third research question: RQ3. What are the effects of the resource interaction patterns on the resource constellation?

3.4 Data collection

Case study research often implies multiple sources of data (Yin, 2013). In this study, interviews, seminars, conferences and other secondary data sources have formed a basis on which to build a case study of the process of starting up in the Swedish energy system and creating an understanding of what for me is a relatively new empirical context being explored. The interviews and seminars conducted in 2015 helped with orientation and guided me to the selection of suitable study objects. In total, 31 interviews were carried out in the course of the study.

When the USONET project started in 2015, I attended two seminars and conducted one interview with a business coach at Chalmers School of Entrepreneurship (now Chalmers Ventures) and one with its director to get a sense of how entrepreneurial projects are carried out. Chalmers School of Entrepreneurship was a natural choice of an empirical context for several reasons, the main one being its strong connection to a technical university where most projects are developed out of a technical idea or product. Given the desire to study interaction and technological development in business networks, specifically for start-ups, Chalmers School of Entrepreneurship was well suited. The incubator connected to the School of Entrepreneurship is based on surrogate entrepreneurship, which means that technology developed by a researcher, company or private person is transferred to an entrepreneur (Radosevich, 1995) or, in this case, the students at Chalmers School of Entrepreneurship. Surrogate entrepreneurship is proven to have a positive impact on venture performance (Jo & Lee, 1996; Lundqvist, 2014), and Chalmers School of Entrepreneurship, in particular, has performed very well in different entrepreneurship rankings. Hence, as the research dealt with interaction and technological development in business networks, there was an opportunity to find suitable study objects in close distance. In total, eight interviews were carried out to capture the entrepreneurial context, including with the business coaches and several other start-ups that were not part of the study.

3.4.1 Approaching the context of the Swedish energy system under transformation

When the project *Technology-based start-ups as engines for renewable energy* started in 2017, I had no in-deep knowledge of the characteristics of the Swedish energy system. What was known was that it was undergoing a huge transformation to make it a 100% renewable system. This knowledge was gained from news sources in general and by following the Swedish Algae Factory and Aqua Robur cases in particular. Having a front row view of the difficulties of changing an already established structure to accommodate renewable energy technology, such as the micro turbine, provoked not only frustration but also curiosity about the challenges. To gain an overview, I began a collection of data from various reports published by the Swedish Energy Agency that not only provided numbers regarding the current use of different energy sources but also proposed scenarios for a potential future. A review of literature describing the history of the Swedish energy system explained the development of the system, the results of which are seen today. There was also an opportunity to carry out eight interviews with people involved in this transformation, ranging from big energy companies to the incubators that help start-ups, researchers and government bodies. These can be seen in Table 2. Much information was also received from homepages, news articles, the Nordic Clean Energy Week[9] conference in 2018 and a visit to E.ON's local energy system in Simris. There was also an opportunity to share the research at the Energy Demo Day in 2019 arranged by the Swedish Energy Agency. Email contact with the Swedish Energy Trade Organisation regarding clarifications on the power availability of their member companies was also helpful.

[9] The European Commission and the Nordic Council of Ministers hosted the Ninth Clean Energy Ministerial and Third Mission Innovation Ministerial (CEM9/MI-3) in May 2018. Companies, politicians and authorities from around the globe met in Copenhagen and Malmö to accelerate the green transition.

Table 2. Interviews related to the Swedish Energy System under transformation

Interviewee	Date of interview	Additional email contact	Aim of interview
Director and senior advisor at E.ON (+ site visit to the local energy system in Simris)	23/05/2018	Yes	To understand the challenges and possibilities for large established energy companies in the transformation
Business developer at Preem	15/05/2018	Yes	To understand the challenges and possibilities for large established energy companies in the transformation
Business developer at the Swedish Energy Agency	11/12/2018	Yes	To understand the investments being made by the government to transform the Swedish energy system
Project leader of ENERGO at Johanneberg Science Park	01/03/2019	Yes	To understand what help the start-ups need to become established in the Swedish energy system
Communication manager at Loccioni	05/03/2018	Yes	To understand how an established firm wants to enter the Swedish energy system to build the case of 'Starting up in the Swedish energy system'
Researcher in innovation and sustainability at Chalmers University of Technology	18/12/2017	No	To get an overview of the challenges the Swedish energy system is facing

Researcher in transformative change at Chalmers University of Technology	28/11/2017	No	To get an overview of the challenges the Swedish energy system is facing
Former director of Energy Area of Advance and innovation advisor at Chalmers University of Technology	28/05/2018	No	To understand the challenges of bringing new technology into the energy system

An Excel file with all the projects the Swedish Energy Agency has financed between 2008 and 2018 was also made available for the purpose of the study. As there was no list of all the start-ups that had been financed by the agency in that time, the aim was to identify all the projects aligned with start-ups and thus get a rough overview of the type of start-ups that were aiming to become part of the Swedish energy system. Moreover, there was curiosity over the types of innovations they wanted to introduce to the system. In order to create a list of all the projects related to start-ups, all large companies, such as Volvo, SKF, etc. and research institutes, as well as some other organisations that were known not to be start-ups, were removed. Thereafter, the names of all the remaining companies were searched for on the allabolag.se homepage to identify the years in which they had been registered and the types of companies they were. Companies that were more than five years old when financed were removed. Approximately 50 start-ups were identified and put together in a list.

3.4.2 Selection of start-ups

When the study started in 2015, it had a broad research focus. Besides the USONET project described above, no specific research question guided the choice of study objects. Instead, this decision was informed by the initial aim of wanting to study how start-ups, as newly established firms with few business relationships and a clear need to develop them, interact in the business network. The choice of start-ups was driven by my personal interest in sustainable development and product solutions. Reading the homepage of the School of Entrepreneurship, several interesting projects were identified; some of these were still running and others were no longer based at the school. In 2015, contact was made with two projects that were still running at the incubator, namely WaterWeave and Aqua Robur. The focus of the first was on developing a smart textile to clean water and of the second, a turbine to produce electricity sustainably. Another start-up founded in 2012, Swedish Algae Factory, which was trying to develop application areas linked to algae, was also contacted. This start-up was located at the Stena Center, which provides serviced offices for entrepreneurs and start-ups close to Chalmers University of Technology. Furthermore, by using my previous personal contact with the CEO of Mevia, a start-up developing a smart package for medicine intake, an initial interview revealed that the start-up was selling products at the time. This was of significant interest and meant that there were now four start-up cases with exciting products that could help explore how start-ups interact in the business network. Unfortunately, WaterWeave eventually dissolved as a project, resulting in only three study objects.

When the second study started in 2017, much greater focus was put on renewable energy technology and thus Mevia was omitted from the study. Adding a third start-up to the two remaining study cases, Swedish Algae Factory and Aqua Robur, meant providing a specific explanation for what had so far not been covered by the study, thus adding to the analysis of connected resource interfaces. In this case, Swedish Algae Factory's application area was related to solar panels and Aqua Robur's to hydropower. When it came to Modvion, the purpose was to add variation to the analysis and thus provide additional understanding of the phenomenon of resource interaction in business networks. Furthermore, there was interest in studying a third energy source, namely wind. Modvion met this criterion and was able to bring something new to the table by providing a case study of a start-up that was introducing new renewable technology into the wind turbine industry, in this case by developing a large stackable tower from wood to be used in wind turbine solutions. Furthermore, it turned out that this could provide additional insights into the implications of having a resource with low degree of explored versatility.

During the data collection and analysis, it became clear that even though the start-ups stemmed from the same context and all had technology-based products, their ways of interacting in business networks were very different. As time went on, the subcases revealed different resource interaction patterns and showed that the three cases could provide a specific explanation of a contextually based technological development process and, at the same time, a general explanation of the phenomenon of resource interaction in business networks.

3.4.3 Conducting interviews with the start-ups in their network contexts

In order to grasp how Aqua Robur, Swedish Algae Factory and Modvion work with resource interaction, data were collected retrospectively and in real time. For the latter case, interviews were the main source of data. According to Kvale (2001), interviews are a suitable way of collecting data as they go beyond everyday discussion and provide in-depth knowledge about a certain phenomenon. Interviews are considered a flexible method of data collection (Easton, 2010) that opens up new topics for discussion, which is highly relevant when studying how things evolve over time.

Interviews were conducted with the CEOs of the three start-ups, each one lasting an hour. To get a clear picture of what was going on in the interaction it was important to interview also the counterparts in the relationships. Several key relationships with counterparts connected to Swedish Algae Factory and Aqua Robur were selected, including those with important development partners, potential users and business partners. Interviews were then carried out with each counterpart. Each interview, except the one with the development strategist at Sotenäs, was recorded and transcribed shortly after it was finished. In some cases, clarification was gained through follow-up emails or additional interviews. The interviews were conducted between 2015 and 2019. By allowing a few months to pass between the interviews with the CEOs it was possible to follow up changes in the relationships. By conducting semi-structured interviews, which Bryman and Bell (2015) describe as a flexible interview process that allows for new topics of discussions, the interviewees were able to talk about important issues and events. This led to redirection in the empirical world and the theoretical framework, as described in section 3.3.

With regards to Modvion, one interview was carried out with the CEO, as no initial orientation interviews were necessary since the specific topics for discussion were already known. One interview was also carried out with the coordinator at the Swedish Wind Power Technology Centre (SWPTC) to understand the process of building the wood tower on Björkö. Furthermore, two masters theses (Ekblad & Stromblad, 2018; Steen, 2017) provided detailed descriptions of how the tower was developed together with other partners. All 15 interviews (Preem excluded) are explained in more detail in Tables 3, 4 and 5 below.

Table 3. Interviews related to Swedish Algae Factory in its network context

Interviewee	Number of interviews	Date of interview	Additional email contacts	Aim of interviews
CEO and founder of Swedish Algae Factory (founded as a project in 2012)	6	17/03/2015 23/04/2015 18/11/2015 13/05/2016 20/06/2017 23/03/2018	Yes	Main source of data and study focus
Development strategist at Sotenäs Symbioscenter	1	20/06/2017	No	To understand the context in which Swedish Algae Factory tries to embed its innovation
Preem (as above)	1	15/05/2018	Yes	To understand the context in which Swedish Algae Factory tries to embed its innovation

Table 4. Interviews related to Aqua Robur in its network context

Interviewee	Number of interviews	Date of interview	Additional email contacts	Aim of interviews
CEO and founder of Aqua Robur (founded as a project in 2014)	5	30/03/2015 27/11/2015 13/05/2016 17/03/2017 03/04/2018	Yes	Main source of data and study focus
User and tester (Kretslopp och Vatten)	1	24/03/2017	Yes	To understand the collaboration between Aqua Robur and its developing partner/user

Table 5. Interviews related to Modvion in its network context

Interviewee	Number of interviews	Date of interview	Additional email contacts	Aim of interviews
CEO and founder of Modvion (founded as a project in 2015)	1	23/04/2019	Yes	Main source of data and study focus
Coordinator at Swedish Wind Power Technology Centre	1	06/11/2019	No	To understand the building of the wood tower on Björkö

3.4.4 Additional data sources

In addition to the interviews, other types of data sources were relied on for updates on the progress of the three start-ups. All three start-ups had functioning webpages from which news and updates on application areas were continuously accessed. Furthermore, Aqua Robur and Swedish Algae Factory could be followed on Twitter. Another valuable source of information was newspapers, such as *Göteborgsposten* and industry magazines. Visibility seemed to be important for the start-ups to attract attention and hence create opportunities for collaboration and financial investment. Swedish Algae Factory also took part in the radio show 'Vetandets Värld' on Swedish Radio P1 (Renström, 2016), which covered the algae cultivation in Sotenäs. All these updates helped to provide a clear picture of what was happening at the start-ups and the opportunity to add information to the case descriptions and identify questions for further interviews. Moreover, several master's theses conducted at Chalmers University of Technology relating to the design of the new algae cultivation system in Sotenäs (Dankis, 2016) and the development of Modvion's wood tower (Ekblad & Stromblad, 2018; Steen, 2017) were available for the purposes of the study. These were of great value for understanding the adaptations of the technical parts of the tower. There was also an opportunity to read a 'learning journal' (a type of diary) from the CEO of Aqua Robur's first year as an entrepreneur at Chalmers School of Entrepreneurship. Moreover, visits were paid to the algae cultivation facility in Sotenäs, which provided an insight into the context in which Swedish Algae Factory operates, and Aqua Robur's pilot facility in Mölndal.

3.5 Reflection on research quality

When it comes to the research quality of case study research, Dubois and Gadde (2014) stress two important issues. The first regards the presentation of the case study and how it relates to theoretical concepts, i.e. overcoming the problem of seeing case studies simply as rich descriptions of events put into pre-existing theoretical categories. The focus should be on matching the evolving case with the evolving theoretical framework (Dubois & Gadde, 2002). In this doctoral process, theory has guided data collection and, vice versa, data have guided the search for new theoretical concepts. A more detailed description of the matching process of the study has already been presented in section 3.3.

The second issue regards the explanation of the methodological procedure underlying the case study. Piekkari et al. (2010) emphasise the reflexivity of the process as an important element. This is because it needs to be emphasised that the flexibility that comes with conducting case studies does not mean that there are no boundaries to what can be considered ‘good’ case research. Instead, reflection on the research process should guide the understanding of the findings as well as the strengths and weaknesses of the study. Dubois and Gibbert (2010) emphasise the importance of transparency with regard to the interplay between the method, theory and case, i.e. in terms of the research process, the matching of the theoretical framework and the case as well as the methodological choices. Thus, the overall intention of this method chapter is to describe the research process as close to the reality as possible without making it too complex.

Consequently, the following paragraphs in this section present some reflections on the study in this thesis. Each choice made during the study has had consequences, some of which should be reflected on further, i.e. the choices that have affected the findings of the study. In addition, in the final chapter of the thesis a comment is made on the formulated contribution in relation to the analytical generalizability.

3.5.1 The choice of selecting certain study objects

As the starting point was taken in technology-based start-ups, the choice of study objects was based on several factors: my own personal interest in technical solutions, being in the context of a technical university, and an assumption that studying industrial firms to capture interaction processes in the business network would be of interest due to the complexity of the innovations. The focus of ‘starting up in the Swedish energy system’ was based on the two start-ups Swedish Algae Factory and Aqua Robur and led to the choosing of an additional study object with a technical solution. The strength of choosing three technology-based start-ups in the context of ‘starting up in the Swedish energy system’ is twofold. First, it enable analysis of the complex process of being a start-up with a hardware solution, which, as the CEO of Modvion expressed: *“demands a greater effort and so it is a bit more challenging”* when it comes to making it useful in the energy system. These technologies are not only add-ons to an existing solution but require efforts when it comes to both adapting current infrastructure and creating acceptance. Nevertheless, these innovations are of utmost importance in the transformation of the energy system. Second, by choosing three study objects that operate in different energy-related areas it was possible to capture a variety of the resource combinations involved and thus add to the picture of ‘starting up in the Swedish energy system’. To build the case and subcases, multiple sources of data were used and the data triangulated (Yin, 2009). For example, an understanding of the new empirical field was gained through attending seminars and conferences related to the transformation of the energy system. Books, reports and news articles also provided a grasp of the history of the energy system leading to its current state and descriptions of future scenarios. Interviews also confirmed the challenge of transforming a system that has been refined according to 'the old' logic. Furthermore, the network around the study objects was captured by interviewing some of the actors involved in the development process of the technical solutions.

Another remark is related to the role of the three subcases and how they complemented each other. SAF and Aqua Robur had been part of the study during the whole time and thus several interviews were conducted before Modvion became part of the study. Thus, the data collection of Modvion included a much smaller number of interviews than the others. However, as the study object was a result of a new empirical direction with the aim to add variation to the analysis it played an important part in creating an understanding of resource interaction in business networks. Hence, together the three study objects complemented each other when it came to capture both different energy sources, and additional analytical dimensions related to the eight categories of connected resource interfaces. In addition, each case description was sent to the entrepreneurs for a final validation and approval of content.

3.5.2 The choice of network boundaries

Another issue to reflect on is the drawing of network boundaries. This is not an easy task, and following Halinen and Törnroos (2005)'s suggestion of letting the research problem guide the boundaries, the problem of relying too much on the focal firms' view of their relationships could be seen early on. This was an issue during the first part of the study leading up to the licentiate thesis, during which the focus was on analysing the focal resource interface and its connection to another directly connected resource interface. By widening the perspective and instead redirecting the analysis towards identifying resource interaction patterns in resource constellations it was possible to capture a broader view of the concept of connected resource interfaces in business networks. However, it is impossible to capture all resource interfaces due to the limitations of time and the memories of the interviewees. Hence, the resource constellations captured in the study were chosen to reflect the most critical embedding processes of the focal resources for each start-up and consequently involve the critical actors in the business network. To clarify, critical resource constellations are those considered to have resulted in the focal resource being shaped towards becoming a useful resource in the energy system.

As Dubois and Gibbert (2010, p. 135) stress: *"a good case study provides a model of reality, not the reality itself."* Thus, when relating the focal resources to the resource constellations of the energy system, the aim was not to show all the resources that build up the system but a simplified picture of the resources (or resource structures) that can influence, and be influenced by, the embedding of a new resource. For this reason, it was important to include in Chapter 6 two levels of analysis of both the specific resource that directly connects the focal resource to the resource constellation of the energy system and the ‘vaguer’ resources, those that are built up by other resources to act as illustrations of the indirectly connected resource interfaces in the respective parts of the energy system.

4. Starting up in the Swedish energy system

An energy system encompasses everything from energy sources to transformation, distribution and use of energy. A country's sources of energy are very much determined by its geographical and economic characteristics. In Sweden today, the dominant energy sources are nuclear power, oil and renewables. After being transformed, energy is distributed as electricity, fuel, district heating or district cooling to be used in factories, offices, private households and services, or transportation[10].

Today, the Swedish energy system is under transformation to meet the target of achieving 100% renewable electricity production by 2040 and zero greenhouse gas emissions by 2045[11]. The success of this transformation will depend on the willingness to open up the system to new actors, technology and forms of capital[12]. Being a new actor with the aim of starting up in the Swedish energy system is therefore about relating to what currently exists, such as other actors, technologies and infrastructure. To be able to understand what new actors must relate to and what changes need to be made, and by whom, it is important to outline the characteristics of the system and, accordingly, describe the major milestones in the development of the Swedish energy system to the present day. Hence, this case description of starting up in the Swedish energy system will begin with the development of the Swedish energy system. This is followed by a description of the current transformations in the Swedish energy system in order to explain the context in which start-ups try to embed their innovations. Thereafter, the journeys of three start-ups to enter the Swedish energy system are described.

4.1 The development of the Swedish energy system

The development of Sweden's energy system is a result of both good access to natural resources, such as wind, water and forestland, and political interests related to oil prices and debates around nuclear power (Nilsson et al., 2004). Historically, the Swedish government has played an important role in creating the energy system as we know it today. As pointed out by Kaijser (1994), Sweden makes an exception when it comes to the government

[10] Statens energimyndighet, 'Energisystemet', *Energimyndigheten.se*, 2015, http://www.energimyndigheten.se/om-oss/press/energisystemet/
[11] Miljö- och energidepartementet, 'Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna', *Regeringen.se*, 2016, https://www.regeringen.se/contentassets/b88f0d28eb0e48e39eb4411de2aabe76/energioverenskommelse-20160610.pdf
[12] SOU 2018:15, 'Mindre aktörer i energilandskapet – genomgång av nuläget', *Regeringen.se*, 2018, https://www.regeringen.se/493036/contentassets/e28a6df38620442d91a39015c27fc276/mindre-aktorer-i-energilandskapet--genomgang-av-nulaget-sou-201815

ensuring the energy supply for its citizens. It has gone from initiating policies to prevent fuel poverty due to forest devastation in the 17th century to building and running the national electricity grid system in the beginning of the 20th century and stimulating the expansion of nuclear power in the mid-20th century. Government involvement has enabled the current infrastructure and business relationships that have been shaped over decades. Moreover, the different energy sources used in Sweden during previous centuries have gone from being small scale for local use to being transformed and used on a larger scale. Today, products such as electricity are also transported over long distances.

4.1.1 A brief historical account

In the 16th and 17th centuries, firewood was the main source of energy supplying Sweden's industries and households (Kaijser, 1994). During the second half of the 18th and beginning of the 19th century, coal imports increased and hence competed with firewood as an energy source. Coal was used in steam engines and gas plants together with firewood, which was still the most used energy source at that time. In parallel, hydropower was used on a smaller scale, often in mill towns, to replace hard manual labour, such as for grinding flour and sawing wood[13]. During the 19th century, many important innovations saw the light of day and started transforming the energy system into its current form. The gas plant was one such innovation, as it enabled centrally produced gas to be distributed through a grid system located below the ground. This was the first system in Sweden by which energy could be transported to users rather than only being used locally. Most gas plants were built and run by municipalities to ensure the provision of fuel for gas lamps and industrial processes[14]. In parallel, and with the historical gas system in mind, Thomas Edison developed the direct current system and established the first power plant in the US. This innovation spread to Sweden where coal became the first source of energy to be used in power plants to produce electricity. During the 1880s, 80% of electricity was produced by coal power plants, however its geographical distribution was limited by the use of direct current technology (Kaijser, 1994). In Sweden, this resulted in small-scale power plants built and run by municipalities and private actors to provide citizens with electricity for heating, lightning and power (Lalander & Gradin, 1984). Additionally, in the late 19th century two further innovations were introduced: alternating current technology and the transformer. Consequently, it was possible to transmit electricity over long distances using high voltage

[13] Rodin, A, 'Vattenkraftens betydelse', *Vardavattendragen.se*, 2015, http://www.vardavattendragen.se/SiteCollectionDocuments/faktablad-vattenkraftens-betydelse-A4.pdf
[14] Kaijser A & Kander, A, 'Framtida energiomställningar i historiskt perspektiv', *Naturvårdsverket.se*, 2013, http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6550-8.pdf?pid=6648

and thus make use of hydropower generated far away from cities. An inevitable outcome of this innovation was the expansion of the electricity system in the late 19^{th} century. Due to the high costs of developing the hydropower stations, regional energy companies were established to develop new ones and to connect small and local stations to larger regional ones (Kaijser, 1994). By taking advantage of new technology, a regional electricity system could be built that allowed energy companies to profit from large-scale electricity production that not only reached urban citizens but users across whole regions (Åberg, 1956).

One important issue during the late 19^{th} century was related to the ownership of the waterfalls that were used by hydropower plants. The Swedish government owned many of the largest waterfalls in Sweden and not making use of them was considered a waste of resources. Instead of selling the ownership rights to private companies, a motion proposed that the government should oversee the expansion of hydropower in the northern parts of Sweden, a proposal that was positively received by the Swedish Parliament. Consequently, in the beginning of the 20^{th} century the Swedish government established the government-owned company Kungliga Vattenfallsstyrelsen[15] (Vattenfall), with the purpose of expanding hydropower and building main lines to connect the current regional energy systems to the large hydropower plants in the north. Since new technology was needed in terms of high-voltage power lines, Vattenfall initiated a collaboration with the Swedish company ASEA (later ABB Ltd.). Together they developed technology to merge western and eastern regional grid systems and use high-voltage direct current to transport electricity from the north to the south of Sweden (Fridlund, 1999). In parallel, regional companies had built their own lines to connect production to users, and they did not like the idea of transporting electricity via the infrastructure developed by Vattenfall. Instead, they wanted to continue building their own lines, a position which the Swedish government opposed. For more than a decade, Vattenfall and the regional companies fought over control of the main lines. The government proposal that Vattenfall should own all lines above 220 kilovolts was not well received by the regional companies. Eventually, in the mid-1940s, an agreement was reached that Vattenfall would own and maintain all new main lines above 220 kilovolts and the regional companies would own and maintain their existing lines (Bjurling, 1982). Furthermore, a consortium of twelve regional energy companies was established amongst which the profits were divided equally. The requirements for companies joining this consortium were a minimum size and capacity and the joint agreement of existing members. This meant that the twelve regional energy companies created a monopoly market structure in which each was the only actor selling and distributing electricity in its region (Kaijser, 1994). Underneath this layer of national actors

[15] Vattenfall AB, 'Tidslinje', *Vattenfall.se*, 2018, https://historia.vattenfall.se/sv/timeline

were hundreds of municipal, private and cooperative organisations which distributed the electricity locally and sold it to the end-users, i.e. the grid system was comprised, as it still is today, of a national, a regional and a local grid. Hence, in the 1960s, the characteristic 'top-down' system was fully developed, and the Swedish energy system had gone from being independent, local and small scale to hierarchical and centrally governed.

At the turn of the 19th century, and in parallel with the development of the electric power system, the combustion engine was imported to Sweden. Initially it was used mostly by shipping companies, which saw the potential of using diesel engines in their merchant vessels instead of sails. The source of energy in the combustion engine was oil, which was imported from abroad since Sweden had no wells large enough to extract it. Since crude oil needed to be transformed into valuable products such as diesel, three refineries were built in Sweden. The first large-scale refinery was established in the late 1920s in Nynäshamn and played an important early role in the delivery of oil products for various applications[16]. As Swedish industry slowly began to replace coal with oil, and Swedes started to drive cars, there was a need to increase the number of refineries. Hence, in the mid-1940s, Scanraff was built in Lysekil by Sveriges Oljekonsumenters Riksförbund (OK)[17]. In the beginning of the 1950s, oil imports steadily increased as prices fell, and by the 1960s and '70s it was the most common source of energy in Sweden (Kaijser, 1994). Consequently, in 1967 the third large-scale refinery was built by BP Raffinaderi AB in Gothenburg[18]. However, oil prices increased during the 1970s due to unrest in the Middle East, which interrupted the supply – the oil crisis was now a reality. This resulted in a desire by the Swedish government to become more self-reliant rather than totally dependent on other countries to ensure the supply of energy to Swedish citizens (Kander, 2002).

Due to Sweden's desire to be more self-reliant, a government initiative was started during the 1970s to intensify research into nuclear power. The Swedish nuclear programme was initiated already in the 1950s when the semi-governmental organisation AB Atomenergi was given the main responsibility for developing the new reactors (Lalander & Gradin, 1984) and investigating the use of domestic uranium[19]. During this time, ASEA was once again contracted as a main supplier of components. Likewise, the government played an important role in introducing nuclear power, as Vattenfall was the largest buyer of plants (Kaijser, 1994). Before the oil crisis, six nuclear power reactors were already operational in Oskarshamn, Barsebäck and Ringhals but used imported instead of domestic uranium.

[16] Nynas AB, 'Upptäck Nynäs historia!', *nynas.com*, 2019, https://www.nynas.com/sv/om-oss/nynas-historia/upptack-nynas-historia/
[17] OK, 'Oljeraffinaderiet Scanraff', *ok.se*, 2019, http://www.ok.se/historia/agerande-i-kristider/oljeraffinaderiet-scanraff
[18] Preem, 'Beskrivning av Preemraff', 2016, https://www.preem.se/globalassets/om-preem/om-oss/vad-vi-gor/raffinaderier/preemraff-lysekil/a1_ls101_beskrivning-av-preemraff.pdf
[19] SOU 2018:15, 'Mindre aktörer i energilandskapet – genomgång av nuläget'

Twelve reactors were built during the 1970s and ’80s, including the new plant Forsmark, which reduced Swedish dependency on oil from other countries[20]. Oil was still by far the largest energy source in the 1980s, followed by nuclear power, hydropower and firewood (Kaijser, 1994).

In parallel, a discussion was being had in response to the nuclear power accident in Harrisburg in 1979 and the oil crisis of the 1970s. A debate was raised about the importance of reducing the environmental and societal impact of energy production. As described by Jacobsson and Bergek (2004), the main energy issue from thereon was the controversial discussion on whether to shut down the Swedish nuclear power plants and replace them with renewable energy solutions or to keep them. This resulted in an attempt to develop new (and old) types of renewable energy sources and technologies such as biomass, solar panels and wind power. Vattenfall was one actor that invested in all these areas of research, but as the technologies were still in their infancy none became commercially viable (Lalander & Gradin, 1984). For example, solar panels were mainly used on a small scale to transform sunlight into direct current used locally by remote cottages and boats where a lack of electricity was a problem[21]. During the 1980s, several research plants for modern wind power technology were built. The use of wind as an energy source has been recorded historically as far back as the 9th century in Iran, and in 1887 wind power was used to generate electricity for the first time in Scotland[22]. Interest in using modern wind power as an energy source did not materialise until the beginning of the 1990s when Germany initiated subsidies. At this time, the share of oil in the Swedish energy market had decreased from 80% before the oil crisis to 30% at the beginning of the 1990s[23]. Additionally, at the end of the 1980s the concept of sustainable development was introduced and embraced by the Swedish government as a guiding principle in the development of its energy system, mainly by supporting the development of renewables (Nilsson et al., 2004). During a conference in Rio de Janeiro in 1992, the UN encouraged governments all around the world to reconsider their economic development and from now on decrease pollution and the use of non-renewable natural resources[24]. This was not a binding resolution but guided many countries, including Sweden, to include environmental concerns into all sectors[25]. It was the

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[20] Statens energimyndighet, ‘Energiläget 2017’
[21] SOU 2018:15, ‘Mindre aktörer i energilandskapet – genomgång av nuläget’.
[22] Shahan, Z, ‘History of wind turbines’, *Renewable Energy World*, 2014, https://www.renewableenergyworld.com/ugc/articles/2014/11/history-of-wind-turbines.html, received 2019-07-18
[23] Axelsson, M, ‘Det svarta guldet – oljans historia, del 2: Oljan under 1900-talet’, *so-rummet.se*, 2017, https://www.so-rummet.se/fakta-artiklar/det-svarta-guldet-oljans-historia-del-2-oljan-under-1900-talet
[24] United Nations, ‘UN Conference on Environment and Development’ (1992), *un.org*, 1997 http://www.un.org/geninfo/bp/enviro.html
[25] Utrikesutskottet, ‘Regeringens skrivelse 1992/93:13 om FN:s konferens om miljö och utveckling år 1992 – UNCED’, *riksdagen.se*, 1992, https://www.riksdagen.se/sv/dokument-lagar/dokument/yttrande/regeringens-skrivelse-19929313-om-fns_GG05UU2

starting point for countries to seriously consider transforming their energy systems to use renewables. Thus, the transformation of the Swedish energy system was in its early stages.

In addition to the above-mentioned development of the energy system, an important milestone occurred during the 1990s – the deregulation of the electricity market in 1996. A competitive pricing strategy was implemented in which customers were given a more active role in deciding their electricity supplier. However, the distribution of the electricity was, and still is, carried out by the specific regional energy companies. The reason for this is that it is very expensive to build and maintain electricity grids. It is not economical to build parallel grids maintained by different companies. The Swedish Energy Markets Inspectorate operates as a regulator to avoid irregularity and high prices for the users. Furthermore, during the 1990s Vattenfall was divided into production and distribution sides and the ownership of the main lines was transferred to a new company Svenska Kraftnät. Nowadays, the buying and selling of electricity is conducted on the Nordic electricity exchange market where it is sold to energy companies, which in turn sell it to users. Consequently, users make two payments, one for the electricity and one for its distribution[26].

4.1.2 The current energy system

In today's system, the major energy sources are hydropower (11%), nuclear power (35%), oil (24%) and renewables including biomass and wind (28%). The rest of the market is comprised of coal, natural gas and other sources[27]. When it comes to the energy sources and their related infrastructure, they have been developed over many years and used in the same way for decades. There have been a few important milestones during this time that have determined the prerequisites of today's energy system. Figure 3 is adapted from the Swedish Energy Agency's overview of the Swedish energy system[28] from 2018 and shows the four stages of the system: (1) supplying energy sources, (2) transforming the different energy sources into valuable products, (3) distributing the products and (4) consumption of the final products. The first stage presents all the energy sources used in Sweden, such as renewables, fossil fuels and sources from the soil. Thereafter, the various energy sources are transformed into fuel, electricity, heating and cooling using turbines, refineries and power plants. The products are then distributed through grid systems, pipes and vehicles to end-users, including industry and households, or exported to other countries.

[26] Ellevio, 'Om elmarknaden', *ellevio.se*, 2016, https://www.ellevio.se/privat/om-oss/om-elmarknaden/
[27] Statens energimyndighet, 'Energiläget i siffror 2020'.
[28] Energimyndigheten, 'Energisystemet', *energikunskap.se*, 2018, http://www.energikunskap.se/sv/FAKTABASEN/Energisystemet/

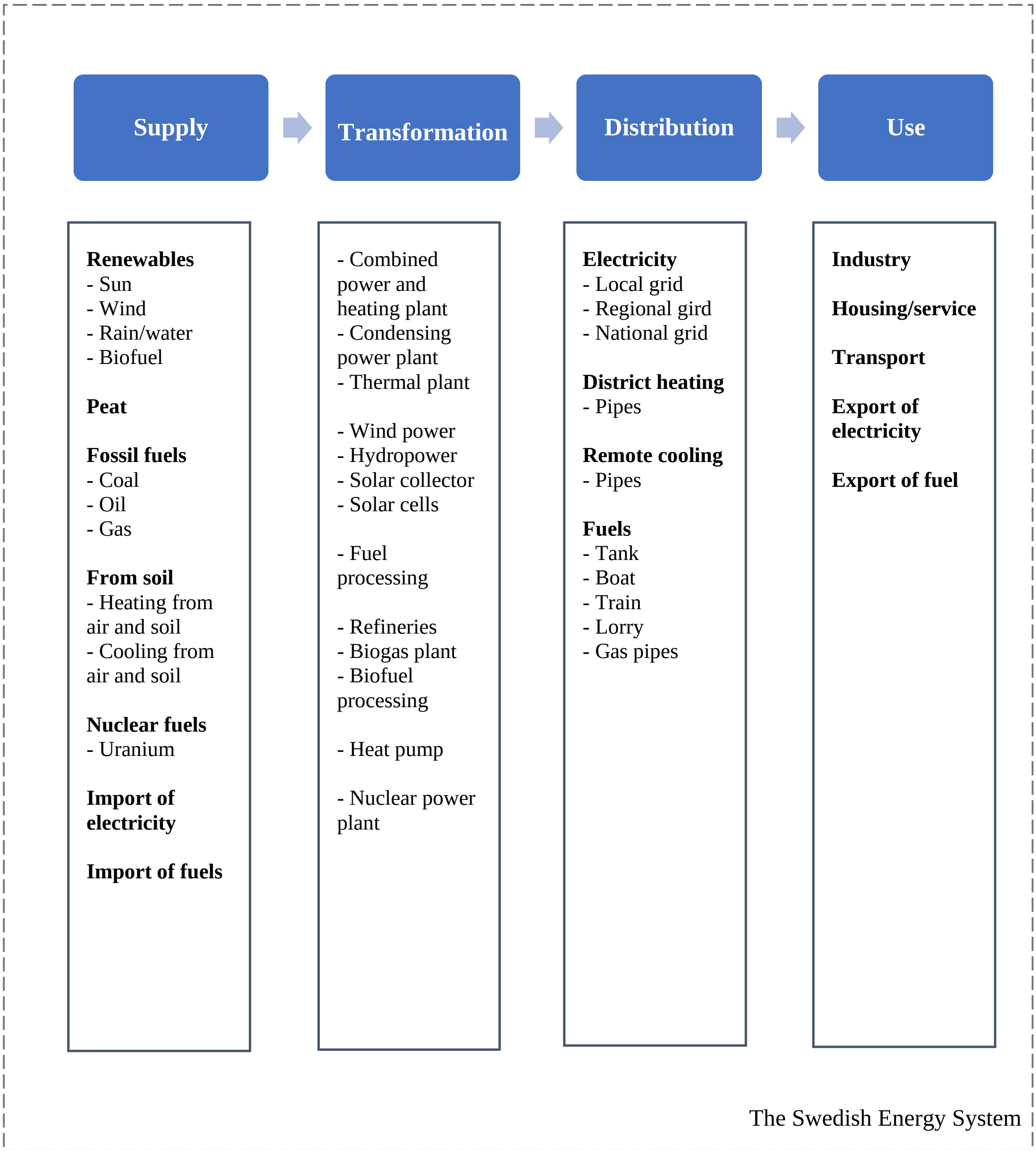

Figure 3. The Swedish energy system. Source: Adapted from the Swedish Energy Agency's figures

A closer look at the actors involved in the four stages, especially the ones related to electricity production, reveals that 36.8% of the installed production is owned by the Swedish government, 34.5% is owned by foreign companies and the rest by municipal companies and other organisations. Due to mergers and acquisitions, the number of actors developing and dictating the conditions of the system has been limited and often involves large corporations. In 2000, three large corporations accounted for 90% of the total electricity production, however in 2017 the Swedish Energy Trade Organisation estimated that the same number only produced 60%[29].

Table 6, adapted from a report written by the Swedish energy trade organisation, shows which companies produce electricity from particular energy sources as of January 2018. Of the total power availability, the largest share comes from hydropower, the biggest producers of which are Vattenfall, Uniper and Fortum. The second largest source of energy is nuclear power, the majority of which is also produced by Vattenfall, Uniper and Fortum, since they own most of the shares in the nuclear power stations. On the other hand, looking at renewables such as wind and solar power, most energy is produced by actors in the category ‘others’, which includes individuals, and small and medium-sized companies. Some are energy companies and members of the Swedish Energy Trade Organisation and some belong to other industries. According to the Swedish Energy Trade Organisation, a handful of its largest members include solar power as part of their business model, but this only account for 10-20% of the total production of solar power. None of these companies publish their figures, hence there is a ‘0’ across this column. However, the trade organisation estimates that within 5-10 years a considerable number of energy companies will invest in large-scale solar power plants[30]. When it comes to wind power, most of the production comes from companies in the category ‘others’, although the largest wind park is run by the member Statkraft Sverige AB.

[29] Energiföretagen, ‘*Elproduktion*’, 2018
[30] Head of statistics at the Swedish Energy Trade Organisation, email conversation, 2018-09-13.

Table 6. The energy companies' power availability in Sweden in January 2018 (in Megawatts)
Source: The Swedish Energy Trade Organisation

Company name	Hydropower	Nuclear power	Wind power	Additional heating	Solar power	Total
Members:						
Vattenfall AB	8 018	4 916	303	402	0	13 639
Uniper (Sydkraft) AB)	1 766	2 242	0	1 198	0	5 206
Fortum Sverige AB	3 063	1 334	42	10	0	4 449
Statkraft Sverige AB	1 261	0	549	1	0	1 811
Skellefteå Kraft AB	656	64	276	54	0	1 050
Stockholm Exergi AB	0	0	0	629	0	629
E.ON Sverige AB	0	0	163	349	0	512
Mälarenergi AB	58	0	0	383	0	441
Jämtkraft AB	212	0	99	45	0	356
Göteborg Energi AB	0	0	31	286	0	317
Tekniska Verken i Linköping AB (publ)	103	0	11	167	0	281
Holmen Energi AB	256	0	0	0	0	256
Umeå Energi AB	153	0	22	57	0	232
Karlstads Energi AB	24	30	0	69	0	123
Öresundskraft AB	0	0	10	87	0	97
Söderenergi AB	0	0	0	97	0	97
LuleKraft AB	0	0	0	80	0	80
Jönköping Energi Nät	20	0	5	51	0	76
Växjö Energi AB	1	0	0	70	0	71
Övik Energi AB	0	0	0	52	0	52
Sollefteåforsens AB	49	0	0	0	0	49
Kraftringen Energi	0	0	4	43	0	47
Borås Elnät AB	12	0	0	34	0	46
Karlskoga Energi &	32	0	0	13	0	45
Eskilstuna Energi &	0	0	0	38	0	38
Gävle Energi AB	15	0	0	23	0	38
Others	179	0	90	391	0	659
Non-members:						
Svenska Kraftnät	0	0	0	640	0	640
BillerudKorsnäs	0	0	0	313	0	313
Södra cell	0	0	0	310	0	310
StoraEnso	0	0	0	151	0	151
Holmen	0	0	0	145	0	145
SCA	0	0	0	97	0	97
Others	423	0	5 086	734	254	6 498
Total amount	16 301	8 586	6 691	7 019	254	38 851

When it comes to the distribution of electricity, the electricity grid system is operated by Svenska Kraftnät at national level, and most of the electricity distribution is carried out by Fortum/Ellevio, E.ON and Vattenfall AB, i.e. they distribute more than half of users' electricity[31]. In addition to these there are about 190 distributors, including approximately 130 municipal companies, according to the Swedish Energy Trade Organisations' statistics[32]. For the production of diesel and other oil-related products, Sweden's three oil refineries are run by ST1, Preem and Nynäs.

In 2015, an agreement was reached by 195 countries to mitigate global warming[33]. The signatories to the agreement were required to work to keep the global temperature rise below 2 degrees Celsius and report emissions and progress towards the implementation of new technology and financial flows[34]. Since then, the Swedish government's main concern has been convincing the current actors in the energy system that decreasing energy production and embedding new technology is necessary to meet the social and environmental concerns of tomorrow. The approaching transformation towards a renewable energy system, seen already in 1992, is now a reality as the Swedish energy system is currently under pressure to achieve 100% renewable electricity production by 2040 and zero greenhouse gas emissions by 2045[35]. Even though the Swedish energy system is performing well today compared with other countries when it comes to providing renewable energy, there is still a need for improvement to meet both environmental and societal demands. As stated by the World Energy Council, transport systems need to be less dependent on oil and politicians have also been advised to find substitutes to nuclear power, as the plan is to gradually phase it out over time. This will not only demand the creation of new technological solutions but also affect existing actors in the system.

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[31] Ellevio, 'Om elmarknaden', *ellevio.se*, 2016, https://www.ellevio.se/privat/om-oss/om-elmarknaden/
[32] Excel file – reports on revenues related to the Swedish Energy Market Inspectorate.
[33] Harrington, R, 'Here are all the countries that signed on to the Paris climate agreement', *nordic.businessinsider.com*, 2017, https://nordic.businessinsider.com/195-countries-that-signed-paris-climate-agreement-accord-deal-2017-5?r=US&IR=T
[34] United Nations, 'The Paris Agreement', *unfccc.int*, 2018, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[35] Prop. 2017/18:228, 'Energipolitikens inriktning', 2018, https://www.riksdagen.se/sv/dokument-lagar/dokument/proposition/energipolitikens-inriktning_H503228/html

4.2 The Swedish energy system under transformation

Due to the above-mentioned climate agreement and other global trends, the Swedish energy system is currently facing a transition. The Swedish Energy Agency[36] points out several factors that will challenge our way of life globally and impact our use of energy. These factors are (1) global temperatures will continue to rise, leading to more heavy rains and temperatures that are too high for farming, placing greater demand in the long run on countries like Sweden to provide food to other countries; (2) poverty will decrease and the level of education increase, leading to an increasing demand for travel and proper housing, and consequently a higher demand for electricity and fuel; (3) environmental and social concerns are becoming more important to global citizens, and thus the demand for sustainable solutions is increasing; (4) the era of digitalisation will encourage new services that transform how and by whom electricity is produced and used via smart grid systems; (5) technical development will continue to accelerate and result in more advanced and competitive products; (6) larger populations due to population growth will increase the need for more housing and electricity, and finally; (7) the combination of population growth, increasing wealth and climate change will increase the pressure on our natural resources such as water and farmland. These seven trends will be determining factors in deciding how energy systems should be developed in the years to come. The actors in the Swedish energy system need to find new ways of collaborating to develop new technology that can reduce energy usage and emissions, as well as provide energy to those who do not have access to it.

As described in the previous section, the Swedish energy system is known for being inert, and the Swedish government stressed in a proposition in 2005 that *"a transformation of the Swedish energy system is a long-term commitment […] its inertia is not only a result of the time it takes to develop new technology but also of the existing infrastructure and investments in current technology, which need to be written off before investments are made in new technology."*[37] The proposition highlighted the situation of an energy system encompassing large and global energy companies which face international competition and are profit driven. Thus, investing in renewable energy solutions aimed only at the Swedish market was not a priority for these companies in 2005. However, after the Paris Agreement in 2015, five of the largest political parties in Sweden came to an agreement and presented three foundational pillars for Swedish energy policy[38]. From now on, the continuous

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[36] Energimyndigheten, 'Fyra framtider: Energisystemet efter 2020', *Energimyndigheten.se*, 2016, https://www.energimyndigheten.se/globalassets/klimat--miljo/fyra-framtider/fyra-framtider-for-skarmlasning.pdf
[37] Prop. 2005/06:127, 'Forskning och ny teknik för framtidens energisystem', *regeringen.se*, 2005, https://www.regeringen.se/rattsliga-dokument/proposition/2006/03/prop.-200506127/
[38] Miljö-och energidepartementet 'Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna'

development of the Swedish energy system should be characterised by diversity of large- and small-scale renewable production that is adapted to both local and industrial needs to meet the aim of creating an energy system that produces 100% renewable electricity by 2040 and zero greenhouse gas emissions by 2045. A step in the right direction was taken in 2017 when the Swedish Energy Agency[39] together with representatives from 20 private and public companies, Swedish municipalities and county councils as well as the Swedish Ministry of the Environment and Energy sat down to discuss how different industries and actors can facilitate the transformation. The government commissioned the Swedish Energy Agency to consider within which sectors it is relevant to develop energy-efficient strategies. The purpose of the strategies is to create general goals for each sector on how to increase energy efficiency and to bring about dialogue between the Swedish Energy Agency, the actors within each sector and the authorities concerned. This approach reveals several benefits, including being able to promote and conduct R&D activities within each sector to enable new technical solutions for industry and environmentally friendly products. It may also lead to better cooperation between actors within each sector as they work towards common goals. The five sectors identified are not necessarily characterised by specific industries but by topic areas in which there is a need for improvements to enable a renewable energy system. Hence, public and private companies, and households are included to plan for the possibilities and challenges that lie ahead.

Five sectors have been identified[40]. ‘Fossil fuel-free transport’ is a sector which accounted for 24% of the total energy use in Sweden in 2015. According to the Swedish Energy Agency, the majority of the energy in the transport sector comes from fossil fuels. Transforming this sector requires efforts to create a society that first and foremost uses more energy-efficient vehicles. Furthermore, efforts need to be made to develop and produce fossil fuel-free vehicles and renewable fuels. The second sector is ‘world-class production’, which represents one-third of the total energy usage in Sweden. Swedish industry has the potential to decrease its energy use in production activities by using better technology and processes such as automation and digitalisation in production facilities. Moreover, it has a key role in leading the way to a circular economy. The third sector is ‘resource-efficient housing’, which includes planning, building and running houses and other types of facilities. In this sector, the priority is to rationalise energy usage and the process by which buildings are cared for. Thus, a life cycle perspective on resource efficiency linked to the construction process and domestic living is important. The fourth sector is ‘future trade and consumption’ and involves sustainable consumer patterns and the importance of having responsible consumers who are educated about products and their ecological footprint. Public actors are

[39] Sektorsstrategier för energieffektivisering (2018)
[40] Sektorsstrategier för energieffektivisering (2018)

important here as they can spread information and set the requirements and standards for products. The fifth sector is 'flexible and robust energy system', which deals with electrification and power. Transforming the energy system into a sustainable one means involving new actors that are not necessarily connected to it in its current form. Going from a system with large electricity plants to small-scale production requires new business models that consider how to use the right amount of electricity, at the right time and by the right people. Furthermore, new roles need to be identified among producers, distributors and users, of electricity, one example being 'prosumers', actors in the energy system able to both produce and consume their own electricity.

The new situation puts pressure on existing actors in the energy system. Taking the electricity sector as an example, the regional companies, which make up the consortium that distributes electricity on the regional net, have had a golden opportunity to influence the government over the years through lobbying. However, as the new situation requires contributions from other types of actors, large energy companies need to reconsider their way of working. One example of a regional distributor is the company E.ON, which previously owned parts of nuclear power stations in Sweden and is one of the biggest actors in the Swedish energy system. Today, all conventional energy production has been sold to Uniper, thus E.ON's business model now focuses on renewable energy solutions and electricity distribution. As a senior advisor at E.ON expressed: *"Our history is characterised by us being an actor that dictates the conditions, and this has become second nature to most of us [working at E.ON] […] historically, we have tried to support our organisation by setting the rules […] we have been part of creating the way the electrical system looks today and now we have the chance to do it again. We can notice the difference from before, where we have not been sensitive to others."* He continues: *"Today, there is a different working climate among us actors, politicians and authorities. This is a new situation; how should we solve it? We have some ideas; others have other ideas and we need to compromise and see where we can end up."* Collaboration across firm boundaries has been one of the keystones when discussing how to overcome the barriers of creating a new energy system. During the Nordic Clean Energy Week[41] in 2018, participants were asked to rate which factors would have the greatest impact on reducing CO_2 emissions in the future. The energy sector highlighted 'collaborating in new ways' as a main priority, followed by 'implementing new business models' and 'changing regulations'. Collaboration between different actors was also highlighted in a report by the Swedish government[42],

[41] The European Commission and the Nordic Council of Ministers hosted the Ninth Clean Energy Ministerial and Third Mission Innovation Ministerial (CEM9/MI-3) in May 2018. Companies, politicians and authorities from around the globe met in Copenhagen and Malmö to accelerate the green transition.
[42] SOU 2018:15, 'Mindre aktörer i energilandskapet – genomgång av nuläget'

which stressed the importance of overcoming the barriers of different traditions and approaches among actors by creating a fruitful environment for dialogue.

It is not only collaboration between actors that is important. New technology is also needed to transform the energy system. For example, oil needs to be replaced by other types of fuel, requiring new technology in vehicles and refineries. Furthermore, electricity needs to be produced in a sustainable way, which will force adaptation between the grid system and the new energy sources. Recommendations to phase out nuclear power, which accounts for 35% of the current energy supply, over time mean that alternative ways of producing electricity have to be developed. On the other hand, nuclear power may act as a frequency controller to balance the uneven production and use of electricity when integrating solar and wind power into the system. From now on, new technology needs to be recognised and existing technology adapted to meet the target of creating an energy system that is 100% renewable. Take hydropower as an example, which is seen as the linchpin of the new energy system. Since energy from other renewable energy sources, such as solar and wind, cannot be stored and thus must be used directly, the energy system is dependent on the supply from hydropower. However, according to researchers at Chalmers University of Technology,[43] existing hydropower technology was developed to work in old energy systems in which there is a stable demand for power and it is clear how much power other energy sources can produce. Using, for example, solar and wind power instead of nuclear power will mean uneven production of electricity in the system, as it is dependent on the amount of wind and hours of sunshine available. Consequently, to avoid disruption in the system, researchers are trying to develop new technology connected to hydropower and adapt it to a more flexible system than before. Another example is transportation technology, a sector which should decrease its greenhouse gas emissions by 70% by 2030[44]. New types of fuels are needed, such as those produced by biomass, in order to phase out fossil fuels like diesel and petrol. One example is the use of liquid rosin to produce biofuel. Liquid rosin is a by-product of the manufacturing process of paper pulp at sulphate pulp mills and consists of a mix of substances that make up the resin from the trees. The Swedish fuel company Preem started to use this type of biomass in its refineries in 2010 and is now on the way to extending its production. Biofuel production requires adaptations to existing refineries and investments in new technology to transition away from oil. This is not an easy process, and as one business developer at Preem explained: *"Preem rebuilt a reactor in Gothenburg in 2006, and at that time we had a reactor that normally produced diesel. Then and there we thought we were unique as we could produce fossil and renewable products in the same refinery […] we rebuilt it two years ago and today we are rebuilding it again to increase our*

[43] Nordin, A, 'Vind- + solenergi= ny utmaning för vattenkraften', *chalmers.se*, 2018, https://www.chalmers.se/sv/styrkeomraden/energi/nyheter/Sidor/Vind--+-solenergi=-ny-utmaning-för-vattenkraften.aspx
[44] Sektorsstrategier för energieffektivisering (2018)

renewable production of fuel […] this is a hard process since these are structures that have existed for many years and we are very keen on not disturbing the production in the refinery […]." The business developer also emphasised that companies like Preem may face the biggest challenge of all since they need to radically and quickly decrease the production of a product that is their livelihood today. Furthermore, Svenska Kraftnät points out that one of the main reasons for developing the national grid system over the coming years is to enable ports to connect it to wind power. Consequently, five ongoing projects in the northern parts of Sweden are running. Moreover, using a larger share of weather-dependent methods for producing electricity demands a good balance between production and use, which means improving facilities such as control rooms and integrating better IT systems. The purpose of this is to give Svenska Kraftnät a better overview of its operations and allow it to balance production and use efficiently[45].

Embedding new technology into an existing system is difficult. The reason for this is not only the predefined infrastructure, as seen in the above cases, but also prescribed policies that do not always support new technology or roles. One example is the newly launched project in Simris between E.ON, the Italian company Loccioni and a couple of other actors, which are trying to create a local energy system[46]. The idea is to use solar and wind power to provide a small village with electricity. Using a battery developed by Loccioni, it is possible to store energy and distribute it later to the households in Simris when there is no sunshine or wind. The project is in a test phase, but E.ON is already concerned about how to eventually scale it up. Storing energy to supply electricity for a whole village using batteries may work for one specific project, but using it on a large scale incorporating multiple batteries and villages requires regulation, as there are currently no rules guiding companies on how to install and operate them. As the senior advisor at E.ON and initiator of the Simris project explains*: "Representatives of the parliament have been visiting the project and asking what regulations need to be changed, so yes, there is an openness to these kinds of projects […] however, there is still a question over what rules we actually will end up with."* Furthermore, the senior advisor stresses the importance of redefining the actors' role in the energy system: *"There are role descriptions in Swedish legislation that clearly distinguish actors that distribute electricity from actors that produce electricity. In the future we may have to review it as the future energy system may not meet today's regulations […] In this case legislation, politicians and authorities need to keep up with change to enable a transformation."* In the case of Simris, new actors such as the households in Simris and the company Loccioni have important roles to play in creating a new type of

45 Svenska Kraftnät, 'Systemutvecklingsplan 2018–2027', *svk.se*, 2017, https://www.svk.se/siteassets/om-oss/rapporter/2017/svenska-kraftnats-systemutvecklingsplan-2018-2027.pdf
46 E.ON, 'Keep track of the local energy system – for real'

energy system. The Swedish government's investigation from 2018[47] anticipates a structural transformation in the energy system that gives alternative 'energy companies' more power. In addition to this, it is important to consider the trend of digitalisation and the impact it has on the current balance between producers, distributors and users of electricity. With the help of technical solutions, households and other firms outside today's energy system may not only produce their own electricity but also be able to distribute and sell it to other users via the grid system. Moreover, firms belonging to other sectors may bring new technology to the system and thus compete with existing energy companies.

4.3 Technology-based SMEs as engines for transformation

One heterogenous group of actors that try to bring new technologies to the energy system is small and medium-sized enterprises that have no clear position in the current energy system. They belong to different sectors and struggle with diverse barriers to commercialising their ideas[48]. The Swedish Energy Agency has invested in 200 small and medium-sized enterprises (SMEs) during the last eleven years as a way of supporting their establishment in the energy system[49]. According to one of the business developers at the Swedish Energy Agency, the reason for investing in small and medium-sized enterprises is twofold. On the one hand, there is a need to transform the energy system and therefore for new innovations to decrease CO_2 emissions, not only in Sweden but also internationally. On the other, there is a need to invest in companies that can create both new job opportunities and export revenues in Sweden. Furthermore, and as pointed out by another business developer at the Swedish Energy Agency, cleantech companies are in need of support for different reason. They often face longer lead times from having an initial idea to taking it to market than many other industries, which makes them risky investments for venture capitalists at the initial stage. Additionally, there are regulations preventing the ideas from growing, and the industry itself is often capital intensive[50].

Every year, the Swedish Energy Agency invests SEK 1.5 billion in activities related to research and innovation, of which SEK 160 million is directed specifically at the commercialisation of innovations belonging to SMEs that have immense potential to transform the energy system[51]. Several different financial tools are used to support the SMEs

[47] SOU 2018:15, 'Mindre aktörer i energilandskapet – genomgång av nuläget'
[48] Excel file – all projects the Swedish Energy Agency has financed between 2008 and 2018
[49] Interview with a business developer at Swedish Energy Agency, 2018-12-11
[50] Energivärlden, 'Nu tar smarta fönster steget ut på marknaden', *energivarlden.se*, 2017, https://www.energivarlden.se/artikel/nu-tar-smarta-fonster-steget-ut-pa-marknaden/
[51] Head of Sustainable Business Development division at the Swedish Energy Agency, email conversation 2020-03-18

to develop their businesses and commercialise their ideas, of which the largest is called 'industrial verification and commercialisation'. This tool finances each accepted applicant with on average SEK 7 million. To receive these investments requires a tough evaluation of the company's financial data, technical prerequisites and legal rights. Moreover, each company needs co-financing of 55%, which means that there must be an industrial partner involved in the project. However, as one of the business developers at the Swedish Energy Agency explained, there is a gap in this financial tool since it excludes ideas belonging to firms with no industrial partner or potential customers. These ideas can often be found in newly established firms (or start-ups) that lack business relationships or connections in the sector they want to enter. Therefore, the agency has open calls to support the stages of conceptualising ideas and verification towards customers without requiring the involvement of a co-financing partner. Hence, there is an opportunity to apply for a maximum of SEK 250,000 to continue with product development activities and support the identification of initial customers. According to the agency there is a benefit from demonstrating its support to potential partners and customers when it comes to commercialising the idea. Several parameters are considered when determining eligibility for financing by the Swedish Energy Agency, and three are highlighted as very important: (1) the potential to reduce CO_2 emissions, (2) the amount of energy used by the product and (3) scalability.

The SMEs financed by the Swedish Energy Agency belong to a range of industries, are either well or newly established in their segments, and face a wide variety of challenges as a result. Investments that have been made in the different industries include helping SMEs whose focus is on developing industrial processes and equipment to facilitate sustainable production of a variety of products[52]. One example is Acosense AB's product ACOspector, which uses active acoustic spectroscopy technology to analyse complex chemical and biological production processes. It was founded in 2009 and received financing of SEK 2 million in 2012 to continue its expansion activities. Furthermore, it received money in 2017 and 2018 to focus on introducing its product to market both nationally and globally. Another example is Meva Energy AB and its biomass gasification system, which produces heat for industrial production processes without using fossil fuels. The company was founded in 2007 and received SEK 2.5 million in 2009 to test a cleaning method in the gasification process. The company also received money in 2011 and 2016 to develop a method to decrease the amount of tar and coal in its heating processes. When it comes to young companies, Spira Energy AB is an example which was granted SEK 250,000 in 2018 to conceptualise a new type of compressor. This company was founded in 2017 and manufactures a compressor that can be used in factories to compress air using only 33-50% of the electricity used in the current process. The start-up is planning the installation of its

[52] Excel file – all projects the Swedish Energy Agency has financed between 2008 and 2018

first machines in 2018 and 2019. Another young company is BioShare AB, which was also founded in 2017. The start-up received SEK 3 million in 2018 to proceed with a project in collaboration with BillerudKorsnäs, a Swedish pulp and paper manufacturer, to identify technical solutions in the production of fossil fuel substitutes in combined heat and power systems.

The company Clean Motion AB produces electrical vehicles for urban transportation. It was founded in 2009 and received SEK 4.4 million in 2010 to commercialise its environmentally friendly vehicle concept. The company also received funding in 2011, 2012 and 2014 to a total of SEK 9.5 million. Furthermore, the company Flexiwaggon AB, which was founded in 2000 and produces railway wagons for transporting lorries, received SEK 3.3 million in 2005 and an additional SEK 7.5 million in 2007 to validate and commercialise its solution of using the global railway infrastructure for lorry transportation and hence decrease CO_2 emissions from road traffic. With regard to young companies (or start-ups), there is one called Bzzt Stockholm, which focuses on developing a mobility system for short trips. The start-up was founded in 2017 and granted SEK 1.6 million the same year to develop the system and test its taxi service in a real and commercial environment in Stockholm. Another company, Greater Than AB, which was founded in 2014, has developed a software solution to calculate drivers' fuel efficiency and risk behaviours. By using data from the car, the company can provide consumers with individualised car insurance based on driver characteristics. The company received SEK 4.8 million in 2015 to verify and promote the product.

Of the SMEs within the real estate industry, one company financed by the Swedish Energy Agency called AccessGate AB is developing an ultrasonic water measurement device to facilitate energy optimisation relating to hot water consumption. The company was established in 2002, and in 2014 it received SEK 760,000 to develop a battery-powered measurement device that is installed directly on pipes. Another company, HeatCore AB, which was founded in 2012 and received SEK 13.5 million in 2013, has developed a new resource-efficient technology for heating water in private households. There are also several companies focusing on optical instruments for use in this industry, an example of which is Heliospectra AB. This company was founded in 2005 and focuses on intelligent LED lighting systems for greenhouses. In 2011, the company received SEK 9 million to launch its product on the European market. It also received financing in 2015 to support the installation of a demonstration plant in Qatar. One young company within this area is CalidumCor, which was established in 2017. It makes a new type of wood-fired stove with an efficiency of 90% that only produces a small quantity of harmful emissions. In 2018, the company received SEK 250,000 as a platform to continue developing the idea.

Furthermore, there are several companies related to the solar industry. One example is SaltXTechnology (formerly Climatewell AB), which was founded in 1989. This company has developed a process that involves storing energy in salt crystals to enable efficient solar energy solutions that can provide heating and cooling. The company received SEK 25 million in 2012, an additional SEK 950,000 in 2014 and SEK 5.5 million in 2017 to install demonstration plants and conduct commercialisation activities. Another company is Sol Voltaics AB, which was founded in 2008 and produces SolFilm™, which increases the efficiency of conventional PVs by 50%. In 2013, the company received SEK 50 million to build a demonstration plant for using nano-threads in solar cell production. A further company, Solarus Sunpower Sweden AB, founded in 2014, focuses on developing curved mirrors for use as solar panels. A curved mirror provides a larger surface area for collecting sunlight during the day. The company received SEK 5 million in 2010 to identify international customers and adapt the organisation to commercialise the product. In the wind power segment, a company called Greenbyte, which was founded in 2009, aims to combine modern measurement and modelling methods to provide reliable and accessible data on the performance of wind farms to owners. The company received SEK 750,000 in 2012 to develop a tool that can map locations that have good wind resources. Table 7 provides an overview of some of the start-ups (those younger than five years at the time of financing) that were financed by the Swedish Energy Agency between 2008 and 2018 and consequently hope to be part of transforming the Swedish energy system[53]. It is not a complete list, but it illustrates the large number of start-ups that want to take part in the transformation and to which industries they belong.

[53] Excel file – all projects the Swedish Energy Agency has financed between 2008 and 2018

Table 7. Start-ups financed by the Swedish Energy Agency 2008-2018

Start-ups	Innovation	Industry	Founded
3eflow AB	A system that ensures pipes are empty when not in use	Plumbing Supply	2009
Acosense AB	Active acoustic spectroscopy technology to analyse process fluid	Education, R&D – Scientific & Technical R&D	2009
Adaptum	Technology to restore the function in fridges and freezers	Technical Consultancy – Energy, Environmental & Plumbing Technology	2011
Agrilogik	Mobile separator of fertiliser	Technical Consultancy, Energy, Plumbing Supply	2014
Applied Nano Surfaces Swe AB	Surface treatment technologies to optimise performance of, e.g., combustion engines	Education, R&D – Scientific & Technical R&D	2008
BioShare AB	Transforming combustion installations into biorefineries	Technical Consultancy in Industrial Engineering	2017
Chromafora AB	SELMEXT™ technology to handle waste streams containing dissolved heavy metals	Technical Consultancy – Technical Consultancy in Industrial Engineering	2010

CarboNext AB	Processing biogas and ethanol to carbon structures, heating and hydrogen	Energy, Supply of Heating & Cooling	2014
Clean Motion AB	Zbee is an energy-efficient electric vehicle for short distance transportation of up to three people and small goods	Manufacturing & Industry – Vehicles	2009
Cleanergy AB/ Azelio	A highly efficient Stirling engine for biogas that produces on-demand electricity 24/7	Repair & Installation – Electrical Equipment, Repair	2006
Climeon AB	The Climeon Heat Power system converts waste heat into clean electricity	Technical Consultancy – Technical Consultant in Energy, Environmental & Plumbing Technology	2011
Collimated Chipping Technology CCT AB	Development of industrial processes aimed at the forestry industry	Technical Consultancy in Industrial Engineering	2010
Compower	Small microturbines for small-scale electricity generation	Technical Consultancy – Technical Consultant in Energy, Environmental & Plumbing Technology	2004
Efficax Energy AB	Solarflex is a junction box that connects additional power sources to existing power storage systems,	Manufacturing & Industry – Machinery	2011 – has gone bankrupt

	e.g. when coupling solar thermal panels to water heaters in single-family homes		
El-forest AB	Electric drive systems	Manufacturing & Industry – Agriculture & Forestry Machinery, Manufacturing	2006
Enrad AB	Energy-saving cooling and heating systems	Manufacturing & Industry – Machinery, Manufacturing	2008
ENSY AB	Technology for efficient handling of fertilisers	Technical Consultancy – Technical Consultant in Industrial Engineering	2011
Exeger Sweden AB	Dye-sensitised solar cells	Technical Consultancy	2009
Fibre Tornado AB	Tornado technology to separate water	Technical Consultancy	2007 – dissolved through merger
Greater Than AB	The technology Enerfy analyses drivers’ fuel efficiency and the risk behaviour in their driving	Data, IT & Telecommunication	2014
Greenbyte	Energy Cloud – software used by industry professionals to monitor, manage, analyse, plan and predict every aspect of their renewable energy portfolios	Technical Consultancy – Technical Consultant in Energy, Environmental & Plumbing Technology	2009

HeatCore AB	Heat exchangers for gas driven heating applications	Manufacturing & Industry – Machinery, Manufacturing	2012
Heliospectra AB (publ)	Industry-leading LED lighting solutions for commercial greenhouse growers and horticulture producers	Manufacturing & Industry – Optical Instruments & Photo Equipment	2005
Insplorion AB	NanoPlasmonic Sensing (NPS) technology, with three main branches of operation: battery sensors, air quality sensors and NPS-based research equipment	Construction, Design & Interior Design – Industrial & Product Design	2010
Keijtec Solutions AB	Development of products within transmission, heat engines and storing of electricity	Manufacturing & Industry	2017
Kyab Sweden AB	Measurement and control systems for buildings to lower energy consumption	Technical Consultancy – Technical Consultant in Industrial Engineering	2006 – has gone bankrupt
Lamera AB	Hybrix™ – metallic material produced using the unique and patented micro-sandwich technology of Lamera AB	Manufacturing & Industry	2005
Läppe Energiteknik AB	Equipment for the production of pellets	Technical Consultancy – Technical Consultant	2012

		in Industrial Engineering	
MagComp AB	Energy-efficient inductors and industrial induction heating systems	Manufacturing & Industry – Electrical Equipment, Manufacturing	2004
Metasphere Technology AB	Spherical powders of eutectic tungsten carbides	Iron, Steel	2009 – has gone bankrupt
Meva Energy AB	Biomass gasification system, not dependent on the weather, i.e. sun, wind, rain or waves; makes production processes free of fossil fuels	Construction, Design & Interior Design – Technical Consultant in Construction & Construction Engineering	2007
Midsummer AB	Equipment for cost-effective manufacturing of high efficiency, flexible CIGS thin film solar cells	Manufacturing & Industry – Machinery, Manufacturing	2004
Mindconnect AB	Platform that gives an unprecedented overview of road conditions and how travel times will change through the day	Technical Consultancy – Technical Consultant in Industrial Engineering	2011
Modvion	Develops large and modular wind power towers in composite materials	Technical Consultancy within Manufacturing & Construction	2016
NODA Intelligent System AB	Noda Smart Heat Grid is a platform to optimise the operational	Technical Consultancy – Technical Consultant in Energy,	2005

	management of a district heating network, automatically and in real time	Environmental & Plumbing Technology	
Nordluft Automation AB	Developing a highly advanced drone swarm control system for use in spreading systems	Manufacturing	2017
Optistring Technologies AB	Technology to convert and feed electricity from solar panels into the power grid	Technical Consultancy	2011 – has gone bankrupt
Plantagon International AB	Developing new ways to cultivate food in urban areas	Chemical Products	2008 – has gone bankrupt
Powercell	Fuel cell stacks and systems, powered by hydrogen that produce electricity and heat with no emissions other than water	Education, R&D – Scientific & Technical R&D	2008
Proforestry Sweden AB	Forest plant protection solutions	Education, R&D – Scientific & Technical R&D	2007
Pumpmodule X AB	Develops systems that can facilitate circulation in closed pipes	Technical Consultancy within Energy, Environmental & Plumbing Technology	2015
R Gate Systems AB	Develops a system for doors that can prevent cold or warm air from entering a building	Technical Consultancy within Industrial Engineering	2011
Raybased AB	A system which makes it possible to design	Manufacturing & Industry – Electrical	2009

	applications that control and optimise building functions, such as heating, ventilation, lighting and security	Components & PCBs, Manufacturing	
ReformTech Heating Tech. AB	Heaters and accessories for a diversity of applications	Manufacturing & Industry – Manufacturing	2010
Salmo Scania AB	Developing land-based fish farms	Fish Farm & Agriculture	2015
Scypho Sweden AB/Manetos	Scypho Heat Control, an automated, intelligent heat control system, which allows people to reduce their energy consumption	Technical Consultancy – Technical Consultant in Industrial Engineering	2010
Sensic AB	Gas sensors for harsh environments, such as those which experience high temperatures	Manufacturing & Industry – Machinery, Manufacturing	2007
Smart Innovation Sweden AB	SmartPole®, an environmentally friendly replacement for wood poles treated with coal-tar creosote	Wholesale – Wood & Building Materials	2008
Sol Voltaics AB	SolFilm™ offers module manufacturers a low-cost, drop-in solution to boost conventional PV module efficiencies by 50% via ultra-high efficiency tandem modules	Technical Consultancy – Technical Consultant in Electrical Engineering	2008

Solarus Sunpower Sweden AB	The Solarus PowerCollector™ is a concentrating (and curved), hybrid solar photovoltaic and solar thermal panel	Manufacturing & Industry – Machinery, Manufacturing	2014
SoletAer AB	SoletAer combines solar heat with a built-in heat pump that provides hot water and is good for the environment	Manufacturing & Industry – Machinery, Manufacturing	2013
SootTech AB/Heat Management	Technology for boiler optimisation based on soot blowing for both recovery and power boilers	Technical Consultancy – Technical Consultant in Industrial Engineering	2007
Spira Energy AB	Technology based on a new principle for compressing air; the machine is especially suitable for use in large-scale, cost-effective energy storage of MW size upwards	R&D	2017
Swedish Algae Factory	Develops different application areas from algae such as making solar panels more effective using the silica shell from the algae	Agriculture, Forestry, Hunting & Fishing – Pisciculture	2014
Tomologic AB	Optimisation technology that powers massive computing power and intelligent clustering	Technical Consultancy – Technical Consultancy	2009

	algorithms to increase material utilisation		
Wattguard	Develops systems to decrease the use of electricity in lamps	Electrical Engineering	2012 – has gone bankrupt
W4P Waves4Power AB	WaveEL 3.0 buoy – a point absorber – in which the energy of water waves is converted into electric power	Manufacturing & Industry – Machinery, Manufacturing	2012

4.4 Start-ups approaching the Swedish energy system

Searching for start-ups that can accelerate the transformation to a sustainable energy system is an ongoing activity for the Swedish Energy Agency. However, financial means is not the only important factor when trying to become part of the Swedish energy system. An actor that aims to start up in the Swedish energy system also requires an ability to relate to existing actors, technologies and infrastructure. On the one hand, there is a defined energy system in which a handful of actors produce and distribute most of the electricity and fuels to meet current demand and have influenced current infrastructure and policies. On the other, there are 'new' companies, as seen in Table 7, which are trying to build business relationships with the energy companies to sell electricity or technical solutions, and some that are approaching other potential users and suppliers such as households or other actors outside the energy system. The process of becoming part of the Swedish energy system varies depending on the type of innovation, the size of the firm and the number of existing business relationships. For example, being a medium-sized firm may indicate pre-existing business relationships, which can help in developing a new solution or introducing it to a new market. The company may also have previous experience of launching a new product or have access to existing production facilities. Being a small firm (or start-up) with no or limited existing business relationships or experience, however, may lead to a more complicated process.

Today, many start-ups are trying to develop new energy solutions and become part of the Swedish energy system. A start-up may be a spin-off of another company, a private initiative or a university project. Many of them have in common a lack of existing business relationships, internally and externally of the energy system, as well as the capacity to scale up production. Being a small firm (or a start-up) requires more than just financial support. The Swedish Energy Agency therefore recently launched a new initiative to facilitate the initial stages of establishment by providing SEK 10 million in total to eight 'innovation environments' in Sweden[54]. The reason for this was to strengthen entrepreneurial environments and support cleantech start-ups during incubation activities such as business development coaching and networking activities with relevant partners. One example is the Energo project based at Johanneberg Science Park in Gothenburg. The aim of the project is to strengthen SMEs located in the western part of Sweden as well as to capture knowledge and learning processes.

To illustrate the complexity of becoming part of the Swedish energy system, which is currently under transformation, the journeys of three start-ups follow. One of the start-ups

[54] Energimyndigheten, 'Ny satsning med innovationsmiljöer ska öka kommersialiseringen av energiinnovationer', 2018, http://www.energimyndigheten.se/nyhetsarkiv/2018/ny-satsning-med-innovationsmiljoer-ska-oka-kommersialiseringen-av-energiinnovationer/

is Swedish Algae Factory, which was given SEK 1.7 million by the Swedish Energy Agency in 2017 for the project titled 'Incorporation of efficiency enhancing nanomaterial from algae in solar cells'. The purpose of the project is to develop more efficient solar cells than are currently available using a nanoporous silica shell surrounding a certain type of algae. The next start-up is Aqua Robur, which has not been financed by the Swedish Energy Agency but is part of the Energo project. It is focused on developing a micro turbine to extract energy from water pipes in the city. The energy is then used to provide measurement devices with electricity to measure leakages in the pipes. The third start-up is Modvion, which is developing large modular wind-power towers using composite materials. This start-up received SEK 3.5 million in total from the Swedish Energy Agency between 2017 and 2019.

4.4.1 Swedish Algae Factory

"Frankly speaking, we started with an alga at the end of 2012, and by the autumn of 2013, we had no idea what we were actually doing. You are an entrepreneur; you talk to people and look for opportunities [...]. It was not until the beginning of 2014 that we could start acting I would say, because then we had started to understand the context."

– CEO of Swedish Algae Factory

Swedish Algae Factory and its product solutions

Swedish Algae Factory (SAF) is a start-up in the cleantech industry that focuses on creating environmentally friendly waste water treatments combined with the production of organic algae biomass and a nanoporous silica material. SAF was started in 2012 as a project by two students from Chalmers School of Entrepreneurship (CSE) together with researchers from the University of Gothenburg and its Department of Marine Biology. The project was initially run for one year at the business incubator linked to CSE. The company has eight employees, including one of the original co-founding students from CSE, a cultivation facility in Sotenäs, and an office and laboratory facility in Gothenburg.

It all started on a polar expedition in 2012 during which two researchers from the University of Gothenburg (UGOT) found a new type of algae growing on polar ice. These algae have distinctive characteristics that make them well suited to the Nordic countries – specifically the ability to grow at low temperatures and in low light conditions. With regard for these characteristics, SAF has developed an algae cultivation system that is both surface and energy efficient, and as a result requires less energy to produce the algae. Today, SAF is focusing on creating a business model that includes a circular-economic mindset by transforming carbon dioxide, nitrogen and phosphorus waste into valuable products. In May 2017, SAF received the World Wildlife Fund's global award 'Climate Solver 2017', dedicated to highlighting sustainable innovations, which means that if the application areas developed for the algae reach an international market they will be hugely beneficial to the climate. According to WWF's calculations, SAF's innovation could reduce CO_2 emissions by 21 million tons per year[55]. The type of algae SAF works with belongs to the group known as 'diatoms' and contains various parts that may be useful in different ways. To understand

[55] WWF, 'Svenska innovationer får WWFs globala hållbarhetsutmärkelse', 2017, https://www.wwf.se/pressmeddelande/svenska-innovationer-far-wwfs-globala-hallbarhetsutmarkelse-2560276/

what kinds of products are suitable for commercialisation, SAF is currently testing the algae's use in several applications with different collaborators.

The first area of application is in waste water treatment. Algae require nitrogen, phosphorus and carbon dioxide to grow. Growing the algae in waste water can provide nutrition to the cultivation system in an environmentally friendly way at the same time as cleaning the water. When the algae have been harvested, the biomass they produce can be transformed into, for example, bio-crude oil by exposing it to a high temperature and pressure. Bio-crude oil is suitable for producing fuel and phosphorus-rich biochar, a charcoal that can contribute to the process of recycling phosphorous. Due to their unique characteristics, the algae make it possible to produce biofuel in an energy-efficient way, as they do not need artificial light or heating during cold periods. The nutrition-rich biomass can also be used as an ingredient in fish food. Moreover, the silica shell surrounding the algae can be removed and used in various industrial applications. Since it is a nanoporous material, which is both insulating and antireflecting, it can be used in, for example, solar cells and batteries.

SAF's business model is still under development, and discussions are being held regarding the suitability of applications from both short- and long-term perspectives. The main objective is to develop an algae-based waste water treatment system that also produces algae biomass. Today, there are customers interested in the waste water treatment system, and this has enabled a first demonstration plant at which the algae can grow by cleaning the waste water from a nearby fish farm. The plan is for the plant to become part of a closed system within which one part's waste becomes the other's material. The idea is to focus on selling the biomass as an ingredient for fish food and to make use of the silica shell in various applications before approaching the bio-crude oil and biochar industries.

Involving potential customers and other partners at an early stage of the product development has been an important way of evaluating different potential application areas for the algae and adapting their characteristics to suit existing user requirements and production processes. By initiating discussions with partners, new knowledge has been gained and some discussions have ended in closer collaboration. Today, several R&D collaborations are being run in parallel to test various applications.

Developing the environmentally friendly waste water treatment system

One of SAF's longest and closest R&D collaborations, which is still running, is with UGOT. The collaboration has opened up opportunities for SAF to use laboratory equipment that would normally be difficult to access. The two researchers who found the algae in 2012 both work at UGOT, and they started conducting tests on the algae already back then with regard to cultivation techniques. UGOT is developing the material (i.e. the algae), which SAF in turn is trying to market and pass on to other collaboration partners to test and develop new applications with. In 2015, the researchers at UGOT were able to use a greenhouse located in an inner courtyard in the Botanic Garden in Gothenburg to study how fast the algae grow and their absorption of nutrients. By measuring the initial nitrogen and phosphorus content of the algae and finding out how fast they grow, the researchers learned how much nitrogen and phosphorus the algae absorb. Using different laboratory techniques, including spectrometry, they were able to measure the amount of nitrogen and phosphorus in the water. With this as a starting point, the production process of the algae could be adapted to achieve a desired growth rate.

The research at UGOT required access to waste water. SAF therefore turned to Renova Group (Renova), a waste management company that works in waste and recycling in western Sweden. As the current water cleaning process was becoming costlier and it was not possible to send the water to the municipality for cleaning, Renova saw an opportunity to develop an alternative way to clean it. SAF and Renova teamed up in a project sponsored by Vinnova (Sweden's Innovation Agency) that allowed SAF to use the waste water from the municipality to conduct the tests in the Botanic Garden. As a result, SAF had free access to the water while testing the suitability of the algae for use as a waste water treatment system for municipalities. However, the tests showed that the nutrition content of the waste water fluctuated too much. On some days, the nutrition level was high and on others it was significantly lower, which negatively impacted testing. As time went on and discussions were held over where to use the water treatment system, SAF looked at the fish farming industry and the possibility of cleaning the waste water it produced. The water used at fish farms has a high and constant level of nutrition, and since the water comes from the ocean, it is obviously saline. Hence, it became clear that the focus should be on cultivating saltwater rather than freshwater algae. In parallel with developing a waste water treatment system, SAF investigated possible uses of algae biomass.

Developing the biomass applications

SAF established an R&D collaboration with Preem, Sweden's largest fuel company, which sells petrol, diesel, fuel oil and lubricating oil, back in 2014. The project was also supported by Vinnova and included Imperial College London as a third party. The project aimed to evaluate whether the bio-crude oil developed from the algae biomass could be used in Preem's refineries, and hence if it would be possible to transform the bio-crude oil into other useful products such as diesel or plastics. During this project, SAF and Imperial College London provided an analysis of the composition of the bio-crude oil, which they presented to Preem. After looking at the composition, Preem confirmed that SAF's product was of interest and that there was a possibility that diesel and plastics could be produced from the bio-crude oil. Furthermore, Preem gave valuable feedback on the need to reduce the amount of nitrogen in the bio-crude oil. Consequently, SAF added an extra step to its production process at UGOT to extract the proteins in the bio-crude oil and thereby reduce its nitrogen content.

SAF's intention with this project was to develop a biomass application and build a customer relationship with Preem. By selling the bio-crude oil to Preem, the company would be able to produce diesel and other products in a more environmentally friendly way than with its current refining processes. Even though Preem proved that it could process SAF's bio-crude oil in its existing plants, the company had no intention of continuing its R&D collaboration with SAF and, as a result, the relationship was gradually dissolved. As the business developer at Preem explained: *"We work with a couple of these kinds of companies [start-ups] and a critical criterion for us is the potential to reach a large enough volume [for the production] [...]. Also, the maturity of the technology and how the patents look are important factors since we often want to protect the ideas we are investing in."* Since SAF did not have large-scale production of biomass at that time, the criterion of reaching a large production volume may have been the factor that put a spanner in the works. Immediately afterwards, SAF saw potential in using the results from the project for future R&D collaborations with other potential customers. However, this application area is no longer relevant as new applications for the biomass have been found. The CEO of SAF expressed the following thoughts regarding the end of the R&D collaboration with Preem: *"When I joined this project I was probably a bit naive and thought that of course everyone wants to invest in a renewable future, with SAF providing renewability and oil companies seeing its importance. But I can see that they didn't want to take the risk."*

Shortly after, an actor in the plastics industry contacted SAF wanting to finance parts of the coming demonstration plant with the aim of becoming a future customer of the bio-crude oil. The actor saw a need to use renewable material in its plastic production and the importance of supporting start-up companies in the industry, for example by financing a demonstration plant. Meetings were held between SAF and the company to discuss how a long-term collaboration could be carried out. Unfortunately, SAF's contact stopped working at the company. There was also a risk that SAF could be tied as a supplier to a company that focused on pressing prices and thus easily changed supplier rather than building long-lasting buyer-supplier relationships. Consequently, SAF decided to end the discussions as there was a risk of ending up in bankruptcy when being forced to lower its price for the biomass.

As time went on, the focus changed again to developing a nutrient-rich algae biomass that not only recycled phosphorus but also produced omega-3-rich oil through its chemical reactions. During 2016, SAF gradually moved away from the oil and plastics industry and started to investigate other application areas such as ingredients for fish food and antibiotics. The start-up initiated discussions with two actors that were willing to buy the biomass for use as an ingredient in fish food but not until the demonstration plant was up and running. A third actor was interested in creating medical drugs from some of the peptides found in the biomass. A researcher at UGOT was also involved in testing the latter application. A fourth actor saw a possibility of using the biomass in fertiliser, as the amount of phosphor in it makes it particularly suitable for use on farmland. All these initiatives were welcomed by SAF, however the same situation arose as with Preem – the potential partners wanted to see the demonstration plant and outputs before investing. For SAF, it was a catch-22: no investment meant no demonstration plant and hence no product to sell, and no product to sell meant no investment. One way to deal with this was to focus entirely on the silica shell and hope to sell silica products from the demonstration plant to cover the costs of expansion. The potential for using the silica shell for various applications was already apparent in 2015, and development activities were intensified in 2016 as the focus was put on developing an application for the silica shell to raise much-needed revenue.

Developing the silica application

SAF started to contact actors early on to test different applications for the silica (SiO_2) that surrounds the biomass and accounts for 20% of the algae. The silica contains three layers of nanopores, each with its own nanopore size, and the nanopores are interwoven through channels in which essential nutrition and light are transported to the algae cell. This is a unique material that has a high strength-to-weight ratio. It is also insulating and antireflecting, which makes it difficult and costly to synthesise in laboratories. These characteristics naturally opened up possibilities for using it in a number of different industrial applications.

In 2015, a company located in France tested the possibility of using the silica shell in batteries. However, as the silica shell contains oxide, the company had difficulty proceeding with the tests. With pure silicon electrodes, it is usually easy to tie the atoms to the lithium ions and thus charge a battery. However, when there are oxides in the electrodes there is no silicon to tie the lithium ions to as the oxides take their place. Unfortunately, neither the company nor SAF had the resources to find a third actor that could remove the oxide to make the silica useful. Nonetheless, SAF could still offer a good material with rather high capacity and environmentally friendly characteristics in future collaborations. In parallel, a second actor in the field of chromography wanted to test the possibility of using the material in its equipment. However, the company required not only stable production of the silica but also certain characteristics of the silica in terms of homogeneity. At this point, assuring homogeneity on a nano scale was not something SAF could achieve and hence the discussions came to nothing.

Another potential application was related to cosmetics, with one actor being keen to buy a finished material but not wanting to take part in the development process. SAF already had the ability to achieve the quantities of silica that were required, but this time its internal vision put a spanner in the works. As the CEO said: *"We have to feel comfortable with what we are doing. As we have said before, our foundation has always been the 'save-the-world' perspective, and you don't save the world through cosmetics."* Instead, this view steered SAF towards improving energy efficiency and the application of silica in solar cells and thermal insulation.

In late 2015, after reading an article in *Nature* that implied that the use of silica shell in solar cells could increase their efficiency by 30%, SAF contacted a solar cell company in Sweden. After presenting the silica, the company was positive about starting testing of the product by sending material and discussing how it could be applied to the solar cells. Tests related to the newly discovered application were also conducted in parallel at UGOT, and weekly meetings between SAF and UGOT were held to discuss their progress. Tests were also conducted in parallel at the Research Institute RISE in Stockholm. The following years of testing showed that the silica shell's antireflective characteristic resulted in a 4% increase in efficiency of silicon-based panels and 60% in forthcoming dye-sensitised solar cells. However, solar panel producers have long R&D cycles, and integrating the material directly into their production processes would take at least five years. Furthermore, the solar panel producers wanted to see a large-scale production of silica.

Another potential application with relevance to thermal insulation was investigated in parallel and stemmed from the idea of using silica in solar cells. SAF contacted Chalmers University of Technology and learnt that this was a possible application that certainly offered a larger potential market than that of solar cells. The plan was to get a positive response from the researchers and to conduct testing before approaching potential customers. SAF had many irons in the fire and, in parallel with developing the application areas for a waste water treatment system, biomass and silica, the start-up looked at how algae could be produced on a bigger scale whilst minimising its environmental impact by having a circular-economy mindset.

Developing a production facility in Sotenäs and having a circular economy mindset

In the summer of 2015, an initiative was undertaken in a small village on the Swedish west coast to create an industrial symbiosis cluster. By taking the commonalities between the use of ocean resources and the marine food industry as a starting point, the project tried to locate several actors in close proximity that could use the waste water from fish farms as inputs to produce other products, hence creating a circular production flow. The plan was to let the company Rena Hav AB build a biogas facility that could make use of the biowaste from the food production at Orkla Food AB, Leröy and other actors in the area to produce electricity and heat that they could use in turn. Additionally, the company Smögen Lax wanted to build a land-based fish farm that could provide the biogas facility with biomass in return for hot water. There was also a possibility of using existing infrastructure to remove used water from the fish farm via a connection to Orkla's pipes. SAF saw an opportunity to be part of this symbiosis as the algae it produced had the potential to clean used water whilst at the same time enabling the harvesting of silica and biomass. In the middle of 2016, most of the prototype facility in the Botanic Garden was moved to Sotenäs.

Before joining the project in Sotenäs, discussions were initiated with potential partners on the possibility of investing in the planned demonstration plant. In total, there were five potential partners of interest, including one government actor; one industry actor in Denmark, which was also interested in buying biomass as an ingredient for fish food; and one actor close to the location in Sotenäs. Discussions were also undertaken with two larger actors in the field of automation and control with regard to automating the future plant. SAF's strategy was to have five options ready in parallel to provide the opportunity for direct production once the application areas were set up. By doing this it hoped to reduce costs and shorten the time to market for SAF's products.

The plan with regard to the two larger actors in the field of automation and control was to involve them in delivering a system to harvest the algae in the planned production plant. However, it proved difficult to involve large corporations in the project. One problem that arose was a dependence on a contact person. This became apparent when the project stopped during holidays. The reason for this was the absence of people in the corporation who could shoulder responsibility for it.

As time went on, discussions with the two actors in automation and control dissolved. The plan was now to develop the harvesting technique together with a partner close to Sotenäs, specifically AH Automation, which was considered more flexible and able to help out with both the harvesting technique and the automation. AH Automation was also conveniently located near the site of the new plant, which allowed it to work directly on site to enable efficient development of the new harvesting technique.

In 2016, the prototype plant in Sotenäs started to take shape outside Smögen Lax's facility. The plan was to test if it was possible to purify the water from Smögen Lax's fish farm by letting the algae feed on the nitrogen and phosphorus in the water. Furthermore, the company Rena Hav AB, which has the same owner as Smögen Lax, wanted to use the biomass from the algae as an input for producing biogas. Early on, the demonstration plant consisted of several shelves stacked on top of each other in a garden house located in the backyard of Rena Hav AB and Smögen Lax's facility in Sotenäs. Hence, a prototype fish farm was built by Smögen Lax to which SAF could connect its algae cultivation plant. This was a good opportunity for SAF to get access to water to measure the productivity of the algae. Furthermore, 7 grams of silica per week could be harvested and sent to laboratories to study its use in solar cells. In connection to this, a master's thesis project was initiated at Chalmers University of Technology to design an industrial-scale algae cultivation system (Dankis, 2016). The master's thesis project was a result of a plan to expand the fish farm and connect it to Orkla and Leröy. SAF could then use 3000m^2 on top of the fish farm for its algae cultivation.

During the master's thesis project, Rena Hav AB, Smögen Lax and SAF all took part in identifying and expressing their requirements and prerequisites. As the companies already had specifications for the pisciculture project, the master's thesis student had to align these with SAF's need for flexibility to continue studying new application areas. The project led to a suggestion for a new cultivation system for SAF that would be flexible and hence adaptable to the different customer requirements that could arise in the near future. To integrate the algae cultivation system on top of the fish farm, Rena Hav AB and Smögen Lax would have to install a pump to the fish farm to pump up the waste water to the cultivation. The algae would then clean the waste water from the farm while, at the same time, an evaluation could be made of SAF's attractiveness as a water cleaning actor. SAF would also extract silica for various applications, with the strategy being to use the test plant as SAF's first commercial plant for silica production. Smögen Lax started building the full-scale facility in Sotenäs in late 2017 with plans for its commercialisation in 2020.

Before achieving a full-scale facility as proposed in the master's thesis project, a pilot plant was operationalised in spring 2018, which could produce 500 grams of silica per week and had an area of 260 m^2. The pilot plant will continue to be used to evaluate the water treatment system and use of biomass as a fish fertiliser for Smögen Lax until the full-scale facility is ready. At the same time, Swedish Algae Factory is sending its silica shell to Gothenburg to extract the silica for different uses. The aim is to eventually scale up the plant into an industrial facility. However, in the end of 2018 there was a setback when the county administrative board declined a future fish farm in Sotenäs after the land and environment court expressed concerns regarding the release of nitrogen and phosphorus.

Using the UV characteristic to attract the first customers

The tests at UGOT continued in parallel with the building of the demonstration plant in Sotenäs. In 2018, the research group published a scientific report in *Nature* that revealed that this specific group of algae could potentially protect itself from ultraviolet light (Aguirre et al., 2018). Optical studies were carried out using microscopy and spectroscopy to describe the interaction of UV light with the algae. It was found that silica shell (SiO_2 frustules) redistributes UV light so it cannot reach the DNA inside the cells while still letting visible light through. This finding strengthened the argument for using the silica shell in solar panels, as by blocking UV light, damage to the solar panels could be minimised, increasing their lifespan. Furthermore, the discovery also opened up a totally new market: the skincare industry.

The tests that had previously been carried out by RISE and UGOT showed that the silica could be used on solar panels to increase the efficiency of traditional silicon solar panels by 4%, and 60% when used in dye-sensitised solar cells. However, as solar panel producers require long R&D cycles to develop a new step in the production process and large-scale production of silica, SAF wanted to develop a component itself to sell to them. There are two different coating materials in solar panels. The first is the antireflective polymer coating used on silicon solar cells to protect the glass and an antireflecting coating put on the glass to absorb as much light as possible. The second is an encapsulant coating which acts as an adhesive between the solar cell and the upper and lower surfaces of the solar panel. Using silicon for this type of coating is advantageous as it absorbs light and provides thermal and environmental stability. Over time, SAF realised that developing and producing its own coating material could be problematic, as it had neither previous experience of producing coatings nor knowledge of the solar panel industry. Moreover, a start-up focusing on both cultivating algae and developing high-quality coatings would be too difficult to manage. As a result, SAF chose to approach established actors in the solar panel industry that already provided coatings to the solar panel producers.

The actors that SAF approached were suppliers of coating materials. Through them, SAF saw an opportunity to avoid becoming an extra step in the production process of solar panels and instead be part of a product already being sold to solar panel producers. Hence, SAF approached a large chemical company that was about to launch its encapsulant coating solution on the global solar panel market. The idea was to make use of the chemical company's infancy in the market and its need to attract solar panel producers. The algae's UV characteristic was one feature that the chemical company could use to market its product to potential customers. The reason for this is that solar panels degrade over time due to the coating being exposed to UV light, a phenomenon that can also be seen in certain colours of paints for houses and other polymer-based materials. Hence, it started to test SAF's silica with positive results, however there was still room for improvements. The chemical company also wanted to see larger-scale production of silica before becoming a customer. Discussions were held with four other global coating companies, one of which initially perceived SAF as a competitor because it would probably own the patent to a joint solution.

As the solar panel market is characterised by a small number of actors and long development processes, SAF started to investigate other potential application areas related to blocking UV light to secure an income. One of these was the skincare industry, and because many UV-blocking ingredients in skincare products are unhealthy and not good for the environment, SAF saw the silica as a valuable substitute to the current ingredients. However, SAF needed EU verification to ensure that silica could be used as a UV filter. Consequently, SAF reached out to large skincare companies to start testing the silica's ability to protect skin from UV light, as they had more power to influence EU regulations. Thus, a partnership was formed with a cosmetics company to test how the silica could be used in its skin products. As the company had its own department for testing new innovations it was much easier to reach someone willing to engage in the tests than had been the case with the solar panel producers. During the first meeting, employees from the marketing, purchasing and R&D departments were present and thus the idea was rooted in the whole organisation early on. Moreover, the company's flexible internal processes for developing new skin products enabled SAF to initiate the tests rather easily. This was not the case in the solar panel industry.

The first tests turned out well and the cosmetics company bought silica from the demonstration plant to continue the testing. Furthermore, SAF has sold silica to several actors within the organic skincare industry to be used as an environmentally friendly moisturiser and cleanser. In the middle of 2018, SAF received SEK 17 million in funding from the EU to develop its demonstration plant and thus be able to achieve yearly production of one ton of algae and hopefully reach a level of silica production that satisfies the needs of coating producers. The goal is to have 100 algae cultivation plants up and running by 2030. The process of finding users and applications has taken a long time due to verifications of the algae. Moreover, the fact that it is a biological material puts extra demands on the way this is done. The long-term perspective on launching products using the algae is something of which the CEO has been very much aware since the beginning. In 2015, she expressed the following thoughts: *"Frankly speaking, we started with an alga at the end of 2012, and by the autumn of 2013, we had no idea of what we were actually doing. You are an entrepreneur; you talk to people and look for opportunities."* She continued: *"It was not until the beginning of 2014 that we could start acting I would say, because then we had started to understand the context. So, you could say that we have been working with* *these algae for just one year and four months, and we are very aware of that. As some people made clear to us, 'you won't be on the market for five years'."*

4.4.2 Aqua Robur

"The major reflection is how hard it is to sell innovations. Even products and services that we (being entrepreneurs and engineering students) perceive as being only slightly innovative, in comparison to what we want to achieve, are hard to convince customers to invest in. The reasons can be old habits or relationships."

– CEO of Aqua Robur[56]

Introduction

Aqua Robur Technologies AB (Aqua Robur) is a spin-off in the cleantech and hydropower industry that focuses on developing a turbine technology for use in water pipes to convert energy into electricity. The company was born out of a course project at Chalmers School of Entrepreneurship (CSE) in 2014.

The technology that Aqua Robur is developing and hoping to commercialise is a result of the need to identify leaks in urban water-supply pipe networks. Today, 20-25% of fresh water is lost as a result of pipeline leaks, and wireless measurement systems need to be installed all over the network to detect them. However, the technology used to supply these measurement systems with electricity is expensive and impractical. Aqua Robur's solution is an urban micro hydro system called Fenix Hub, which enables measurements to be taken even without access to electricity. The system converts a small amount of the water flow in the pipes into electricity using micro turbines developed by the company. An increasing lack of good quality drinking water is one of Europe's major challenges, and in March 2019 Aqua Robur was awarded the European Commission Horizon Prize for Zero Power Water Monitoring worth EUR 2 million[57].

The product solution uses a micro turbine and generator to extract energy from the water flow and turn it into electricity. Additionally, it incorporates a battery to store the electricity it produces and IoT communication platform that can be connected to different measurement devices. The information collected by the system can later be accessed by sewage companies through the cloud. The company consists of one of its original founders (and CEO), a CTO, a product developer and a sales and business developer. Pilot tests are

[56] Extract from learning journal written by the CEO while a student at Chalmers School of Entrepreneurship in 2014
[57] European Commission, 'Winner of the Horizon prize for zero power water monitoring', *europa.eu*, 2019, https://ec.europa.eu/digital-single-market/en/news/winner-horizon-prize-zero-power-water-monitoring

being conducted in Sweden together with a development partner and potential user in the water industry in order to validate the technology. The company is also having encouraging dialogues with other potential users around Europe. The future looks promising as the market for collecting data from infrastructure systems is growing and the demand for suitable power sources for them is high. In a couple of years, Aqua Robur wants to be well established on the Swedish market and seen as the obvious choice for providing flow-based energy sources in water systems. The team also wants to start expanding into the rest of Scandinavia and other countries in Europe. The start-up will then focus on building relationships with distributors and other partners throughout Europe.

Founding of the company

As previously mentioned, Aqua Robur started in September 2014 as a project in the master's programme at Chalmers School of Entrepreneurship (CSE). Part of the second year of the two-year programme requires students to run a project at the CSE-connected incubator, for which they are grouped together with inventors from academia, corporations or independent contexts. The aim of the Aqua Robur project was to commercialise the idea of using turbines to convert water power into electricity. At the beginning of the project, the team consisted of three students and three inventors.

The inventors were all students at Chalmers University of Technology, and their idea of using turbines to convert water power into electricity was inspired by the boat engine technology at one of the inventor's previous workplaces – a world leading supplier of engines and power solutions for marine applications. To facilitate the product development of the turbines, the three inventors started a company together, and in 2013 they patented their idea. However, they did not patent a prototype but parameters for the future product solution. As they had limited time to work on their idea, they decided to turn to Chalmers University of Technology and its incubator for help. In spring 2014, they presented the idea to the students at CSE. During the presentation, the students found the idea very interesting, especially as it came with a patent, and after being put together in a team they began to contact potential investors and customers.

From idea to first-generation prototype

At the very beginning of this journey, the three inventors became inspired by the idea of using rain power to generate electricity in a sustainable way. They realised that in cities like Gothenburg that have high rainfall, it must be possible to use rain power to light up cities.

They transferred this idea to the context of natural water streams and considered the possibility of using kinetic energy in natural water streams to generate electricity instead of letting it go to waste. To achieve this, they realised that it was possible to produce cheap turbines that could generate an even amount of electricity regardless of water flow. The inventors then turned to one of the inventors' previous workplace and its propeller technology for inspiration. A boat's engine uses existing chemical energy such as petrol and converts it into mechanical energy and then kinetic energy, causing it to move. In contrast, a turbine uses the kinetic energy of flowing water and converts it into mechanical energy, which in turn is transformed into electricity by a generator – it works like a boat engine but in reverse. The specific turbine developed by the inventors can extract 10-100 kW and is suitable for harnessing the power generated by small streams of water. The product, which they called Power Shark, was taken to Chalmers School of Entrepreneurship in August 2014.

The students took on the task of building a business around the product and started by contacting potential customers. During this time, its application was intended for conventional hydropower and natural water streams and targeted at customers such as small privately owned hydropower plants in rural areas. The aim was to find a site to carry out technology verification. Even though it was important for Aqua Robur to get customer feedback at an early stage to understand the customer requirements, the team realised the need for networking with other actors in the cleantech and hydropower industries. By doing this, the team became acquainted with the regulatory standards that were likely to impact the implementation of their product later on. Aqua Robur got in touch with the county administrative board to find out the legal processes and difficulties of operating in such an environment. Operating in natural water streams does impose certain limitations due to the specific environment in which a hydropower plant is located. The team concluded that this potential market was a dead end and that they needed to re-evaluate their strategy.

By the end of 2014, Aqua Robur did not have a clear picture of what it wanted to achieve with the venture. However, it understood the importance of a good industry network and making use of the knowledge of potential customers, competitors and partners. After a meeting with Kretslopp och Vatten (K&V), a municipal unit that works with water supply and waste handling in Gothenburg, and an inspiring talk with the chairman of the board, the venture started to change focus to water pipelines in cities. The water cycle starts with a cleaning facility that processes natural water; it is then stored in, for example, water towers to be distributed later to households and other facilities in the area. After use, it goes to a waste water treatment facility where it is cleaned again and then returned to nature[58].

The team began to look deeper into scenarios in which a turbine could be useful for producing electricity from kinetic energy in water streams. They discovered community water systems, which in cities like Gothenburg often overflow due to differences in altitude. When water reaches low parts in the city, it usually does so at high pressure due to gravity. Sometimes there is so much overpressure that the pipes come close to breaking. To mitigate the risk of breakage, ventilators are put on the pipes to dissipate the water's energy. By using a turbine, this energy can instead be converted into electricity and distributed through the electricity grid. At this point, the higher power range of 10-100 kW was still suitable. The aim was to sell the electricity produced by the system to energy companies, such as Göteborg Energi, which would act as middlemen by buying the turbines and operating them at the sewage companies. Consequently, the involvement of the county administrative board would be reduced. However, because the urban water supply pipe network provides drinking water, all of the parts in Aqua Robur's product solution would have to meet the requirements of the Swedish Food Agency on which substances the water is allowed to interact with.

In parallel with the development of the new application area, initial meetings were held with potential thesis students at the Mechanical Engineering Department at Chalmers University of Technology. The purpose of these was to make use of their knowledge to facilitate the technological development of the new application area. The thesis students were a good asset since they did not have to be paid and could work full time during the spring of 2015 on developing the first-generation prototype. In November 2014, the team visited the Norwegian University of Technology and Science (NTNU) in Trondheim and saw an opportunity to make use of its expertise in hydrology science and its hydropower laboratory. Unfortunately, this cooperation ended quite soon after the initial discussions due to the distance. The team perceived it to be more efficient to stay in Gothenburg and use the resources available there.

After valuable discussions, Aqua Robur and K&V, together with Älvstranden Utveckling AB and Umeå Energi, put together a Vinnova application within the programme Utmaningsdriven Innovation (challenge-driven innovation) to finance future tests of the new application. As part of its preparation, Aqua Robur made a visit to K&V's site. Aqua Robur saw K&V as a potential user of its product and wanted to bring it on board early in the product development process. During its first visit to K&V's laboratory, Aqua Robur

[58] Syvab, 'Vattenskolan', *stockholm.se*, 2017, http://webbplatsarkivet.stockholm.se/_sites/www.syvab.se/2017/07_07/information/storsatsning-for-renare-vatten.html

could already sense the next possible application for its product. The CEO wrote in his learning journal at CSE in week 5, 2015: *"As part of the preparation for the application and customer development process we made a visit to K&V [Kretslopp och Vatten] and one of the sites where they currently have a fixed electric installation, a reduction valve and some measurement devices. This scenario is particularly interesting to us since we believe that we can build a good business powering the measurement devices with the turbine."*

The visit to K&V instigated discussions on whether to start focusing on a new application area within the context of water pipes, i.e. the supply of electricity to the measurement devices located on the water pipes instead of distributing it to energy companies. The main goal was now to get a good response from the board. However, this required the students to provide a joint vision for the product together with real data to strengthen their arguments to convince the board. The team members expressed frustration over the lack of data connected to the new application slowing down the process. The first sign of scepticism to running the venture after the graduation in May was now visible. The CEO wrote in his learning journal in week 8, 2015: *"Some stumbling discussions on the concept size decision where we don't really have real data to back up discussions with nor a joint vision,"* he continues: *"[…] I had a more visionary mindset whilst my colleague wanted our dialog to be backed by hard facts, which we currently lack."*

The product development process proceeded with the two master's thesis students to strengthen the arguments to the board. Discussions were held by the team on whether to use an on-grid solution to make use of the overpressure in the pipes and then distribute the electricity to the energy companies, or the off-grid solution, to use a considerably smaller turbine with the aim of operating in a lower power range, 1-10 kW, to supply the measurement devices with electricity. As the CEO wrote in week 12, 2015: *"We had a detailed dialog with our board member about the future from June and our thoughts on the possibility of pursuing the project. We still have different visions for the product concept. I see some major risks connected to the on-grid solutions and business model that my colleagues don't seem to be bothered by."*

Already by this stage, the CEO saw a problem with developing a device that included an on-grid solution. Shortly after this, his concerns were confirmed following meetings with an industry partner that offers technical consultancy services and IT solutions to customers in different areas such as energy, buildings, industry, telecom and infrastructure, and by a company that maintains and improves the pipes supplying drinking water, drainage systems and gas. The discussions opened the students' eyes to how customers in the industry think and act as well as how companies such as the two previously mentioned actually respond. The CEO wrote in his learning journal in week 16, 2015: *"The major reflection is how hard it is to sell innovations. Even products and services that we (being entrepreneurs and* *engineering students) perceive as being only slightly innovative, in comparison to what we want to achieve, are hard to convince customers to invest in. The reasons can be old habits or relationships…The large on-grid [solution] represents a much higher level of innovation because of the changes in mindset, investment calculations, work habits and relations it requires. The small off-grid [solution], on the other hand, can be applied to the general industry norm of standardised product transactions between supplier and buyer."*

The team faced resistance to a product that they thought of as an innovation that could change and improve the industry. However, trying to change a well-established structure in an industry that already has certain operational norms and values is not easy. Several potential customers were called over the following weeks. Also, more data were collected to strengthen the arguments that the low-hanging fruit had already been picked with regard to developing a large on-grid solution. On the other hand, the small off-grid solution was very interesting from a customer perspective.

To understand the needs of potential users and obtain hard facts to present to the board regarding an off-grid solution, Aqua Robur and its thesis students worked closely with K&V during spring 2015. The first stage of the collaboration consisted of a feedback session in which Aqua Robur asked K&V what it perceived to be a good product, knowing that Aqua Robur would go back to its office and think of new concepts while developing the prototype. The team then showed K&V their new ideas and obtained feedback on certain parameters that needed changing. As time went on, K&V made its facilities available to Aqua Robur, which was a prerequisite for Aqua Robur's future development, as its lack of resources, such as money, made it hard to proceed alone. In March 2015, the prototype tests were initiated for its first idea, the on-grid solution. In K&V's laboratory there is a full-scale water pipe in which Aqua Robur was able to install its turbine and measure how much electricity it could generate. These measurements acted as a foundation for the following feedback sessions with K&V. During the collaboration, it became even more apparent that Gothenburg would need to measure leaks in a couple of hundred places in the water supply system.

As well as spending much time establishing good relationships with users and understanding their needs, Aqua Robur considered its future suppliers at an early stage. One contact was established with a supplier of generators located in Kalmar. Aqua Robur preferred approaching small companies that were used to working with start-ups. The company in Kalmar performed one-piece production of generators, and the initial idea was to outsource most of the production to the supplier and for final assembly to take place at the sewage companies. The aim was also to include the supplier in Kalmar in the development process as soon as possible. It was important for Aqua Robur to develop production processes that would suit the future product and to collaborate with suppliers that would share the risks.

Going back to the user side, K&V and the outcome of the tests conducted in spring 2015, it was clear that the on-grid solution was not the right way to go. K&V's only ambition was to provide inhabitants with water. It was not motivated to produce energy and distribute it to the electricity grid to generate revenue. If Aqua Robur were to have invested in developing the on-grid solution, it would have made demands on companies such as K&V to develop closer relationships with energy companies. Questions such as 'Who should own the equipment?' and 'Who will obtain the revenues?' would have been asked. Solving these issues may sound easy, but they are not priorities for the companies in question, nor are they easily handled. Aqua Robur ended up in discussions on whether to lease turbines to the energy companies and put the responsibility on them to operate the turbines at K&V. The feeling was that this could result in complex business models that would put a spanner in the works. On the other hand, implementing an off-grid solution would mean investing in reducing leaks and improving the delivery performance of the water system, which is also K&V's main mission. As the project leader at K&V explains: *"[…] we have old pipes under the ground and we cannot see if they are leaking. We are therefore building new measurement zones so that we can monitor the water pipe network in a different way. […] I'm part of a project to extend the measurement zones with measurement devices; by placing the devices in the soil we are able to measure how much water enters the zone through the pipes and how much leaves the zone."* In other words, the difference in water flow reveals how much water has leaked from the pipes. However, these measurement devices require electricity, and today K&V tries to connect them either to existing power outlets in the city or to batteries. Both can cause problems for K&V as the power outlets may be remotely located, and the batteries will eventually need to be changed.

Finally, in May 2015, Aqua Robur and its board members were convinced to move away from the on-grid solution and go for the off-grid one instead, i.e. using as little energy as possible to produce enough electricity to power the measurement systems in the water pipe system. By doing this, it was also possible to find potential users in flat cities since there was no longer a need to use the overpressure in the pipes. Through the tests with K&V and discussions with other potential users, customers and industrial partners, Aqua Robur decided to meet the users' current requirements instead of creating a problem definition for them.

Developing the second-generation prototype

Going from the large on-grid solution to the small off-grid one meant rejecting major parts of the first prototype developed in spring 2015. After the summer, the focus was put on developing the second-generation prototype, which meant removing parts of the current technology and giving away the patent. The main users were still considered to be the sewage companies, but there was no longer a need to include the energy companies as potential customers for the turbines. Instead, the idea was to reach out to companies selling the measurement devices to K&V. Through these companies, Aqua Robur could make use of existing relationships between K&V and suppliers of measurement devices. In a wider context, instead of selling micro turbines directly to 290 municipalities through public procurement, there was now the possibility of selling the product to only a handful of companies. Aqua Robur's intention was to provide the turbines as part of a complete offering to be sold by suppliers of measurement devices to public sewage companies such as K&V. The tests with K&V continued during the autumn of 2015 with the focus on developing the second-generation prototype, and K&V saw a good opportunity to use the turbine in the future: *"If there is an unlimited amount of electricity, we can transfer [measurement data] more often. So here we have their [Aqua Robur's] product, which is a turbine that can charge this battery. This is a big advantage as we are then able to transfer data more frequently, and we do not need to change batteries to the same extent as we do today."* By integrating the turbine in K&V's test plant at the water treatment plant in Alelyckan, the generator and turbine could be adapted for field tests. The test plant was used to test and calibrate K&V's measurement devices. Using the pipes, Aqua Robur could see how much the pressure in the pipes decreased when energy was taken from the water flow and converted into electricity. The pressure drop needed to be minimised to ensure the water flowed at the desired speed. Many of the adaptations that needed to be made were to the size of the turbine to ensure that it fit in the pipes. Most of the pipes in the system are of a standard size, and by trying to adapt the turbine to these standard pipes early on, Aqua Robur could later approach other sewage companies using the same type of pipes. Furthermore, the generator needed to be adapted to extract the desired electricity level whilst avoiding overly high drops in water pressure. Aqua Robur turned to the supplier in Kalmar, which was willing to adapt its production process to fit the new demand of the coils. Of the components that Aqua Robur ordered off the shelf directly from suppliers, the generator was the one that needed be developed together with the supplier to maintain the desired water pressure. Letting the supplier in Kalmar adapt its production processes to enable a certain type of coil is of course costly, and hence Aqua Robur tried, as far as possible, to order existing products from the suppliers. Moreover, it was not only K&V that was dependent on how much energy the generator would use but also the potential buyers of the turbine. One was a company that develops software solutions for processing the information generated by the measurement devices. As the CEO of Aqua Robur clarified: *"We simply need to see how much water flow K&V can provide us with and how much energy we can provide the measurement devices with as well as how much measurement data the company can deliver to K&V in the end."*

When trying to integrate the turbine with the existing measurement devices at K&V, it became clear that it could no longer be located directly in the soil. The turbine needed to be close to the device and have space around it for maintenance. This made both K&V and Aqua Robur consider alternative ways of locating it in the water pipe network. K&V started to look for existing wells or zones to which water could be fed from several places. By creating a bypass, K&V could also avoid unnecessary stops. Aqua Robur understood that some adaptations were required from its side as well, so it started to develop its own well to make the turbine flexible to install and maintain.

To meet the requirements and make use of the feedback from K&V, and hence develop the second-generation prototype connected to the small off-grid solution, Aqua Robur chose to work with technical consultants instead of large companies. The consultants, often one-man companies, were located in the Gothenburg region and had regular meetings with Aqua Robur. One forum was workshops held at Aqua Robur's office at Chalmers Innovation. Having most of the consultants located in the Gothenburg region was a precondition, as the distance was a determining factor for Aqua Robur. During the autumn of 2015, two consultants worked on the mechanical components of the turbine, including constructing the blades and making sure that the turbine did not leak. Two consultants also worked on the turbine's electrical components and hence developed the generator and programmed the microchips aimed at ensuring the battery charged. The design of the battery was a major task as it had to be aligned with the measurement devices. The consultants working for Aqua Robur were chosen carefully, with many coming from the inventors' own network. As the CEO explained: *"It is really hard to find partners that understand us and newly established firms. It is a bit different working with us. We have quite limited resources compared with some consultants that are used to sending invoices to Volvo, and they cannot charge us in the same way."*

With regard to the forthcoming production of the prototype, Aqua Robur's aim was to build its own supplier network for the turbine. The two other parts, the measurement device and the wireless data transfer unit, would be produced by the device manufacturers. All three parts would then be assembled and sold to the sewage companies through the measurement device companies. The start-up did not see the necessity of using the same suppliers as the measurement device companies, instead it focused on finding suitable suppliers located as close as possible to Aqua Robur's office in Gothenburg. The reason for this was the need for flexibility, as the prototype was still under development and Aqua Robur therefore needed to have frequent contact with the suppliers. Even though it was extremely important for Aqua Robur to find suppliers with which it could build strong and long-lasting relationships, the start-up was now in a phase in which it reached out to several different producers of prototypes. Building a single prototype did not demand a few long-lasting relationships, as opposed to when it is finished and part of serial production. It was therefore hard to strike a balance between, on the one hand, creating relationships with suppliers that would share the risks of the development process and hence open the door to further collaboration and, on the other, keeping enough distance to be able to change supplier if the prototype changed.

Finding suitable suppliers among conventional manufacturing companies required Aqua Robur to work professionally. These suppliers expected a customer that knew about supply chain management and not as the CEO put it ‘a hippie’ entering meetings with crazy suggestions. Aqua Robur had to work hard to conform to the industry standards, as both a user and manufacturer. Operating in a conventional industry sector differs from being, for example, an IT start-up selling consumer products. Instead of building its own image and promoting an innovation it believed in, Aqua Robur had to reduce the scope of the innovation and hence the risks involved in implementing the product, in both the production processes and the water supply pipe networks. With regard to the latter, it was important to promote a product that could be useful in already stable processes and not jeopardise the flow of water to the residents.

In autumn 2015, Aqua Robur searched for other producers of prototypes, mostly within the automotive industry. These companies mainly worked for Volvo and were located in the Gothenburg region. Even though production was a long way off, Aqua Robur started contacting potential producers. These were traditional ‘Gnosjö companies’, i.e. small companies located in the specific area of Gnosjö in Sweden, which could potentially both produce and assemble the product solution. The main criterion when reaching out to potential producers was familiarity working with small companies. While conducting the tests with K&V, new insights could be explored that would have an impact on the choice of supplier. At this stage, it was all about matching the partners’ different requirements. The CEO expressed the following thought on this: *“[...] we go to the customers with our prototype to get their requirements. We then approach our developers who say that ‘this is probably possible [to develop].’ We then ask if this is possible to produce, and the producers reply ‘yes if you adjust this and that.’ Then we have to go back to the customers and tell them what is possible to deliver. Of course, they in turn will have new requirements, so it becomes this nice loop.”*

Installing the first demonstration plants and developing the new solution: the Fenix hub

In 2016, dialogues were initiated with various sewage companies that would be able to test a prototype of the micro turbine in real water pipes in the cities. Even though the pipes may have similar shapes and dimensions there are still differences in how the measurement devices are handled. Some are put directly in the soil, which makes it hard for Aqua Robur to maintain them. Another challenge was related to the communication of the data coming from the measurement devices. It was evident that the data visualisation was outdated. In addition, it seemed difficult to sell turbines exclusively to measurement companies as they had to be matched with the selling of the measurement devices to the sewage companies. By integrating an IT service directly in the product solution, Aqua Robur opened up the possibility of selling a total product solution directly to the sewage companies. Hence, the company that develops the software solution for the measurement devices, would now be a competitor and a customer at the same time. From now on, Aqua Robur had a new product offering called the Fenix hub, which could serve raw data continuously to the sewage company through a variety of interfaces. Several external sensors (or measurement devices) that could take a variety of measurements such as temperature, pressure or flow of the water could now be connected to the Fenix hub and displayed in real time for the sewage companies. In 2018, the new product was installed and tested at Aqua Robur’s office to show potential customers how it works.

Today, Aqua Robur is in discussions with approximately 40 potential users in Sweden and abroad to collect data on how the Fenix hub can be developed further. Pilot tests are also being conducted with customers in Mölndal, Härryda and Nyköping, among other places, which pays for the Fenix hub and allows Aqua Robur to develop maintenance practices and adaptations to provide the best possible service to the sewage companies and learn more about how the product works in practice. Based on the new solution, which includes the turbine, sensors and communication hub, three additional application areas are being investigated in relation to the control and automation of irrigation systems, monitoring of pipelines for district cooling and providing industrial processes through the cloud.

4.4.3 Modvion

"The energy sector consists of many big giants that are not used to working with small companies […] some may have the perception that it is only a current hype and look for the easy way around by using software solutions [developed by start-ups] as add-ons. To present a hardware solution that can really make a huge difference demands a bigger effort and so it is a bit more challenging."

– CEO of Modvion

The idea of building a wind power tower from wood

Modvion is a start-up that focuses on developing modular wind power towers from composite materials. It started as a project at Chalmers School of Entrepreneurship in 2015 when an inventor introduced the idea of building wind power towers from wood to two students. The inventor had previous experience of building boats from wood, and when he saw a 100-metre-tall wind turbine of wood built in Germany he thought there was good potential to develop the idea further. During their year at Chalmers School of Entrepreneurship, the two students developed a business model around the idea, and in 2016 Modvion became a registered company. Today, the start-up has six full-time employees.

The tower developed by Modvion consists of laminated wood sourced from Nordic fir trees. As wood stores CO_2, it is a much more sustainable building alternative than, for example, steel or concrete. Compared with today's turbines, which need time before the environmental costs of building them reach the break-even point, a wood tower will be carbon neutral from the start. Generally, steel and concrete have been preferred as construction materials due to their composition and the relative ease with which their strength can be calculated. Wood, on the other hand, is an anisotropic material with different mechanical properties in all directions because of the nature of its cell structure. Additionally, it is often weak where there have previously been branches, which makes it hard to calculate its strength accurately. However, by cutting it into thin layers and gluing them together these weak areas will be distributed across the material and thus have a negligible impact on its strength. In addition, the development of better computer programs in recent decades has enabled a smoother process of calculating wood structures and thus facilitating the use of glulam beams. As well as building with a sustainable material, Modvion aims to build 150-metre wind power towers to enable greater power generation.

However, building large towers will result in difficulties transporting them on the roads to the wind parks. According to Swedish regulations, there is a maximum width for road-driven lorries. Building a tower with a diameter greater than 4.3 metres will result in a load that is too wide to transport. Consequently, Modvion's plan is to offer the towers in stackable parts, allowing them to fit on conventional lorries. Using wood building the tower according to a specific construction design will decrease the production cost of wind power by 40% according to estimates[59].

Applying the idea to an energy context

Sweden has a good environment for harnessing wind power due to its large area and good wind resources. In 2017, there were 3376 wind turbines installed in Sweden[60] and today more than 10% of the electricity produced in Sweden comes from wind power. The Swedish Energy Agency estimates that there is a need to add 80-120 TWh of renewable electricity production to reach a 100% renewable energy system by 2040. With respect to current technical and economic prerequisites and regulations, wind power is the renewable energy source with the greatest potential. Hence, at least 60 TWh should come from wind power in order to transform the energy system[61]. One way of achieving this is to build taller towers and larger rotors. Rinne, Holttinen, Kiviluoma, and Rissanen (2018)'s study on comparing old wind power technology with the wind turbines being built today showed that the new larger rotors improve the power potential significantly. Furthermore, tall towers can be used in areas where there is not much wind as they can reach higher and stronger winds. Today, there are wind power towers that can generate five to twelve megawatts, which is a huge increase on those developed during the 1990s, which were only able to produce an amount of electricity in the kilowatt range. As Rinne et al. (2018) also emphasise, using large wind turbines means fewer installations and thus less land used.

However, using large wind power towers presents some challenges. For example, there is an increase in the costs of transporting them. The Swedish Energy Agency also addresses the challenges related to the planning stage as there are long lead times and uncertain licensing procedures. Moreover, the grid system and the main lines are at maximum capacity in many parts of Sweden and the expansion of the lines therefore needs to be coordinated with the geographical expansion of the wind power. To be able to meet these challenges,

[59] Modvion, '*Increasing productivity of the world's most competitive renewable energy*', https://www.energimyndigheten.se/globalassets/energivarlden/energivarlden-tema-vind/modvion---otto-lundman.pdf
[60] Statens energimyndighet, 'Statistik över vindkraftens utveckling', 2018, http://www.energimyndigheten.se/nyhetsarkiv/2018/nytt-rekord-for-vindkraften/
[61] Statens energimyndighet, 'Energimyndighetens vindkraftsstrategi', 2018, http://www.energimyndigheten.se/globalassets/fornybart/framjande-av-vindkraft/vindkraftsstrategi-uppdaterad-2018.pdf

the Swedish Energy Agency invests money in various innovative projects such as Modvion's development of a wind power tower in wood. Looking at the value chain of the wind power industry, it consists of a project manager, such as an energy company that both owns and maintains the wind park, or an actor that wants to sell the wind park to the energy companies. The project manager finds a suitable place to establish a wind park and also applies for the required licences to build it. Thereafter, the wind turbines are delivered as a package by the turbine suppliers, which in turn have sub-suppliers for parts such as the rotors, generators and towers. Modvion enters the value chain as a supplier of wood towers to the turbine suppliers, and the turbine suppliers add rotors and generators. Hence, it is important for Modvion to understand the context that the wood tower will be part of and talk to the customers of the turbine suppliers, such as the energy companies, as they are the ones creating the demand.

Developing the first prototype in the northern west coast archipelago

In 2017, Modvion received SEK 2 million from the Swedish Energy Agency to develop the modular wind power tower from wood. The project *'Timber meets wind power: Tall modular wind turbine towers in bio-based structural material'* was the starting point for developing the first prototype of the tower. As the CEO of Modvion expressed: *"It is very different experiencing something in real life to seeing it on a PowerPoint slide. This is an important step [for Modvion], and the next step is to build [the towers] on a commercial scale."* In order to build the first prototype of the wood tower, Modvion had to engage several different stakeholders. Specifically, the project consists of the following main partners: Modvion, the research institute RISE, the Swedish Wind Power Technology Centre at Chalmers University of Technology and Skellefteå Kraft. In addition to the main partners, other companies are involved in developing components for the wood towers, such as the company Moelven, which produces laminated wood products, and the company Pretec, which develops steel components for use in bonds and attachments. In 2017, Modvion received SEK 640,000 from the Swedish Energy Agency to undertake the project 'Timber meets wind power: Development of weather protection' to develop weather protection for the wood tower as it requires certain protection. The colour and coating companies Teknos and RISE have been involved in this project to develop the coating material. In the beginning of 2019, Modvion also received a further SEK 880,000 from the Swedish Energy Agency to verify the results. All the projects are now in their final stages and, in the beginning of 2020, a prototype of a 30-metre-tall wind power tower will be installed on Björkö in the northern west coast archipelago outside Gothenburg.

In the development process, much focus has been put on calculating the structural design of the wood tower. The top of the turbine consists of heavy equipment such as the nacelle, including the equipment used to generate electricity from the wind, the rotor and its blades, as well as the hub that holds the blades. Hence, it is important to use a wood material that can support this weight. To understand which type of wood material and glue to use considering the external factors such as wind and rotor loads, calculations were made both internally at Modvion and externally with collaboration partners. One important partner that helped to conduct tests of the specific components is the research institute RISE. Together with RISE, Modvion analysed the interaction between the tower and the wind turbine in a computer program to calculate possible resonance. In 2017, a master's thesis student of Applied Mechanics identified different loads on the tower to study its force flow. Steen (2017) concluded through her calculations that, rather than use Modvion's proposed baseline diameter of 11.5 metres and using three Laminated Veener Lumber (LVL) layers in each wood sheet, it would be preferable to have a baseline diameter of 12.5 metres and five LVL layers in each sheet to withstand the stress from the wind, rotor, self-weight and tower head. Furthermore, in 2018, two master's thesis students at the Department of Industrial and Material Science at Chalmers University of Technology focused on developing the joints for the wood panels into levels when assembling the future towers at the wind parks. Several concepts were developed and evaluated with regard to the requirements for the wood tower, such as being weather resistant, easy to assembly, able to handle the rotor force and manufacturable using existing production technologies. Ekblad and Stromblad (2018) concluded that tangential and vertical joining solutions needed to be combined. The tangential joins are used to attach the LVL panels to each other horizontally and the vertical ones to build the height of the tower by stacking the modules on top of each other. Specifically, two tangential joining solutions had to be combined, the LVL stair concept in which the inner and outer walls are made up of LVL sheets that are created in stair formations that interlock with an identical panel on the other side, and the steel-side concept which should be used where the LVL sheets are not strong enough. Moreover, there need to be vertical joints, which are the main load-carrying joints. In this case, guided glulam beams would be attached between two LVL sheets together with shorter beams on either side of the glulam beams where bolts can be attached. Furthermore, a two-level LVL step would be used applying the same logic as the tangential LVL stair to interlock the panels on top of each other. Moreover, the joints were verified in fatigue tests conducted in one of the machines located at RISE's wood engineering department.

In parallel with developing the components, Modvion also carried out discussions with the glulam company Moelven regarding how to produce the required beams and LVL sheets. Moelven was established in 1899 in the city Moelven in Norway and started by producing wagon wheels dipped in boiling oil. Today, the company has 3500 employees spread around the world and divided into three divisions: timber, building systems and wood, and the production facility in Töreboda focuses on producing glulam beams. As part of their master's thesis project, Ekblad and Stromblad (2018) carried out interviews with Moelven Töreboda to understand how the production of the wood components could be carried out. In their thesis, the students emphasised Moelven's concerns about the required manufacturing tolerances, within which Moelven was not used to operating in its everyday projects. As the students wrote in a concluding remark in their thesis: *"Moelven's regular work consists of pre-fabricating bespoke glulam beams for buildings, where the tolerance requirements are quite coarse. Constructing a tower like this is a different job altogether, which would require them to alter their manufacturing process [...] if they are not willing to make changes to improve their manufacturing, Modvion may have to look elsewhere"* (Ekblad & Stromblad, 2018, p. 57).

However, Moelven was eager to continue cooperating with Modvion to develop the parts for the prototype to be built on Björkö. The company saw the value of integrating its material in new types of products and thus change the picture of what products wood can be used in. Today, Modvion works in parallel with Moelven's regular production and discusses ideas about construction and manufacturing technology, both for the prototype and the future automated production. To be able to integrate Modvion in the manufacturing facility, Moelven had to adapt to the new requirements, and changes had to be made within the manufacturing facility at Moelven in Töreboda. Moelven made room for Modvion's production line just next to the regular production and assigned part of its staff to work on Modvion's wood components. Moreover, as the tower consists of a mix of different engineered wood products, Moelven uses both its own materials and materials specifically ordered from suppliers at Modvion's request. The production of the prototype has been planned for periods of the year when the facility usually experiences lower rates of production.

Beyond the wood products, there is a need to find suitable coating products to protect the wood tower from the weather. The colour and coating company Teknos has played a huge role, together with RISE, in developing a coating solution. The solution is a compact colour that is sprayed directly onto the wood panel making the tower impenetrable and the moisture level on the inside of the tower easier to control. Having a wood material with a constant moisture level can help manage fatigue loads better and reduce the presence of microorganisms than a material with changing moisture levels. To understand which coating solution to use, Modvion, Teknos and Moelven, together with the other collaboration partners, discussed the best coating solution.

Installing the prototype together with the Swedish Wind Power Technology Centre

One important collaboration in the development of the wood tower is with the Swedish Wind Power Technology Centre (SWPTC). The centre was started in 2010 to gather companies and researchers to study the physical aspects of wind power. Until then, research had mostly been carried out on how to develop the grid system to connect it to wind power. Up to now, the centre has worked on 30 different projects related to how to develop the foundation and rotors, amongst other things, from basic to more applicable and industry-oriented research. A central and important asset of the centre is the wind power pilot on Hönö, which was recently moved to Björkö. On Hönö, new carbon fibre rotor blades were installed that included sensors to measure the load on the blades. Furthermore, sensors were installed in the foundation to measure potential cracks. In the project with Modvion, the plan is to build a prototype of the wood tower on Björkö to learn more about how well it integrates with the other parts, such as the turbine, foundation and rotors.

SWPTC and Modvion are working separately on different parts to prepare for the installation on Björkö. Modvion has mainly focused on developing the tower and getting it ready for installation. At the end of 2019, the outer parts were assembled and ready to be treated with the coating solution. However, there are still internal components to install. SWPTC has focused on laying the new foundation on Björkö with help from the construction company PEAB. Eventually, when the tower is ready to be installed, Modvion and SWPTC will take mutual responsibility and be physically present on Björkö. Currently, Modvion and SWPTC meet once per month to discuss progress and the time frame, and the plan is to install the tower in January 2020. Even before the installation of the wood tower has been carried out, Modvion has signed two joint declarations of intent with Varbergs Energi and Rabbalshede Kraft. Hence, if the test results are positive on Björkö, the plan is to use the experience when building the first 100-metre-tall wood tower together with Varbergs Energi. Moreover, Rabbalshede Kraft has showed interest in buying ten wood towers for its new wind power park outside Töreboda. Consequently, Modvion is planning to build a production line in 2020 to meet the demand for wood towers.

4.5 Analysis of the start-ups' resource interaction in the business network

In order to understand how the start-ups' ideas can be turned into new and useful resources, it is important to understand how the ideas can become useful within both the start-ups' own resource collections and the resource constellation of the network. As Håkansson and Snehota (1995) point out, an element will only become a resource in itself when it has a known use in relation to other resources. Hence, by combining the focal elements of the start-ups, i.e. the algae, water turbine and wind power tower, with other actors' resource collections, new knowledge of how to use the resources can be gained. As these focal elements have what Holmen (2001) refers to as potential use, they will be considered resources in this analysis.

However, combining a new resource with existing resources in the resource constellation of the network can be difficult as the existing ones are often a result of many years of adaptation in relation to other connected resources (Gadde et al., 2010). Thus, it is interesting to examine how the algae, water turbine and wind power tower become useful by analysing the resource interfaces and how they are connected. The resource interfaces are either technical, organisational (Dubois & Araujo, 2006) or mixed (Jahre et al., 2006) and can trigger changes not only in the specific resource interface but also in directly and indirectly connected ones.

The analysis takes its starting point in identifying the interfaces created in critical resource constellations in which the start-ups' try to embed their resources. The connections between the interfaces in the resource constellations are identified and analysed according to the template developed in section 2.4.

4.5.1 Resource interaction of Swedish Algae Factory

Swedish Algae Factory (SAF) is developing several different application areas relating to the energy field for its algae; these include a waste water treatment system, a biomass application and a coating solution for solar panels. In order to understand how the algae can become useful, several different resource ties have been created between the algae and other resources belonging to both the resource collection of SAF and the resource constellation of the network. Two important resource constellations, in which attempts are being made to embed the algae, are analysed below in terms of how the resource interfaces developed between the algae and other resources in the constellation. They relate to two critical development processes for the start-up, i.e. that of biomass as an element in Preem's production processes and the silica shell as an ingredient in coating solutions.

SAF turned to the Swedish fuel company Preem with the aim of developing the biomass application. Together with Imperial College London, the actors initiated a project to evaluate if the biomass could be used in Preem's refineries. The mixed resource tie interface between the algae and Preem's organisational structure revealed the potential of using the algae as a complement to the other renewable products Preem develops. During the tests with Imperial College London, the technical interface between the algae and Imperial College London's facility revealed that the algae resulted in a particular composition of bio-crude oil. However, the technical interface between the algae and Preem's facility showed that the composition of the algae was not compatible with the processes at the refinery. The nitrogen content of the bio-crude oil was too high to ensure the quality of the products. Consequently, to remove the nitrogen from the biomass the technical interface between the algae and UGOT's laboratory had to be adapted, with UGOT having to add an extra step to its algae production process. The change in this technical interface enabled a better match between the algae and Preem's refinery. However, the business relationship ended. One reason for this could be found in the organisational interface between SAF's and Preem's organisational structures. As a start-up, SAF was looking for a partner to share risk and collaborate with to continue developing the application. Conversely, Preem's general procedure when working with start-ups was to find those that could demonstrate potential to scale up production. Hence, since the internal competence on how to scale up the biomass production was missing at SAF, it was not possible to embed the algae in Preem's resource collection and there was no incentive for it to continue the business relationships after the project ended. Figure 4 shows the mixed, organisational and three technical resource interfaces created when evaluating the use of the biomass in Preem's production process.

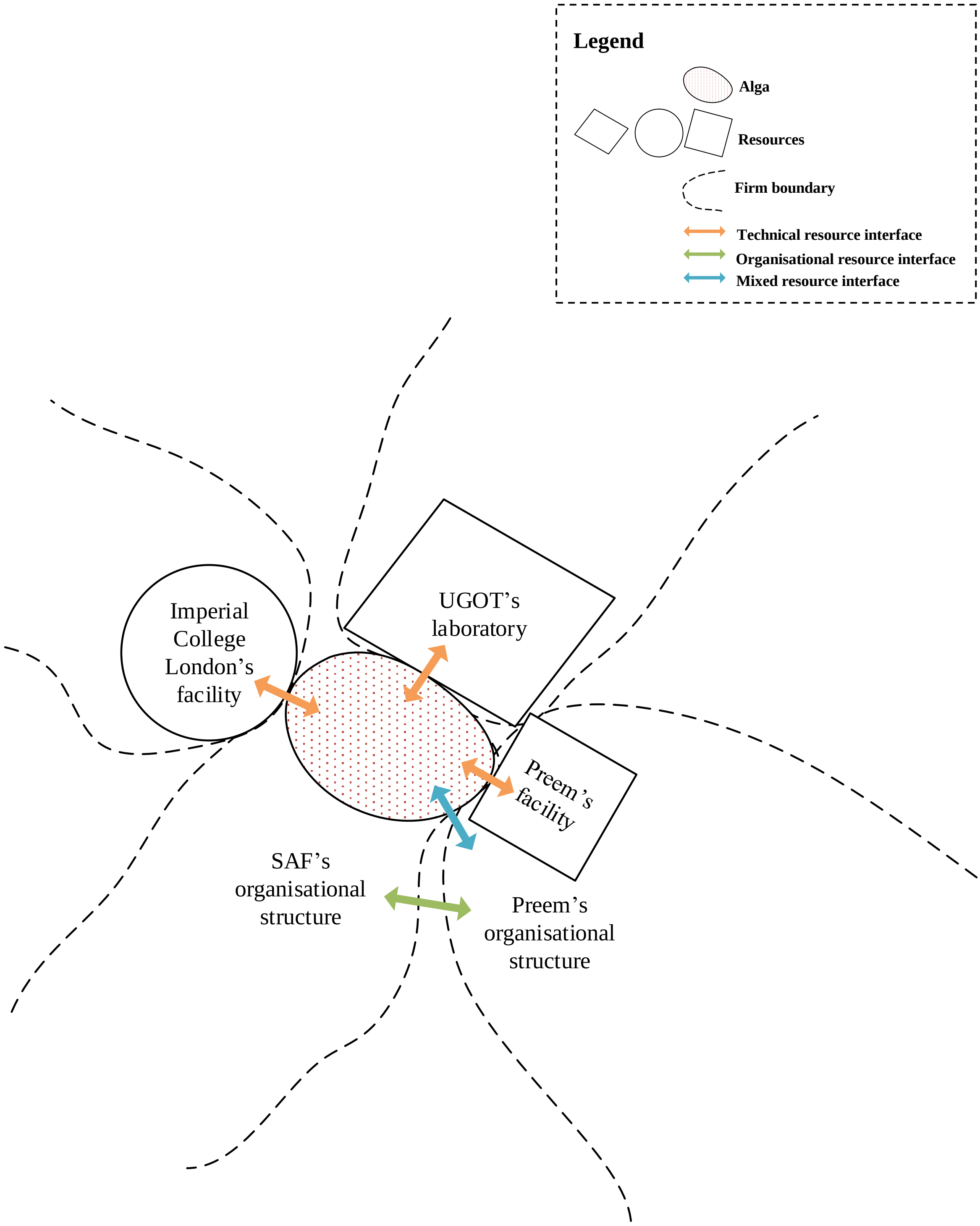


Figure 4. Resource interfaces created when embedding the algae in the resource constellation related to the evaluation of the use of the biomass in Preem's production process

The identified resource interfaces were enabled or triggered to change by another resource interface in the resource constellation. Figure 5 shows the connections of the resource interfaces in the resource constellation that impacted the critical technical interface between the algae and Preem's facility. The mixed resource tie interface created between the algae and Preem's organisational structure revealed an awareness at Preem of the potential of using the algae in its production processes. It was in line with Preem's idea of moving towards sustainable fuel production and thus enabled the directly connected technical resource tie interface between the algae and its facility (1). It also enabled the directly connected technical resource tie interface between the algae and Imperial College London's facility (2). The technical resource tie interface between the algae and Imperial College London's facility triggered the adaptation of features in the directly connected technical resource tie interface between the algae and Preem's facility as a result of the level of nitrogen being too low (3). Hence, the existing (and 'activated') resource structure at Preem was already formed in a way that made it hard to use the algae in its resource collection. Consequently, this triggered a change in the directly connected technical resource tie interface between the algae and UGOT's laboratory (4). The result was a technical resource tie interface between the algae and Imperial College London's facility that indirectly triggered a change in a technical resource tie interface between the algae and UGOT's laboratory (5). However, the organisational resource tie interface between SAF's and Preem's organisational structures eventually dissolved the now functional directly connected technical resource tie interface between the algae and Preem's facility(6).

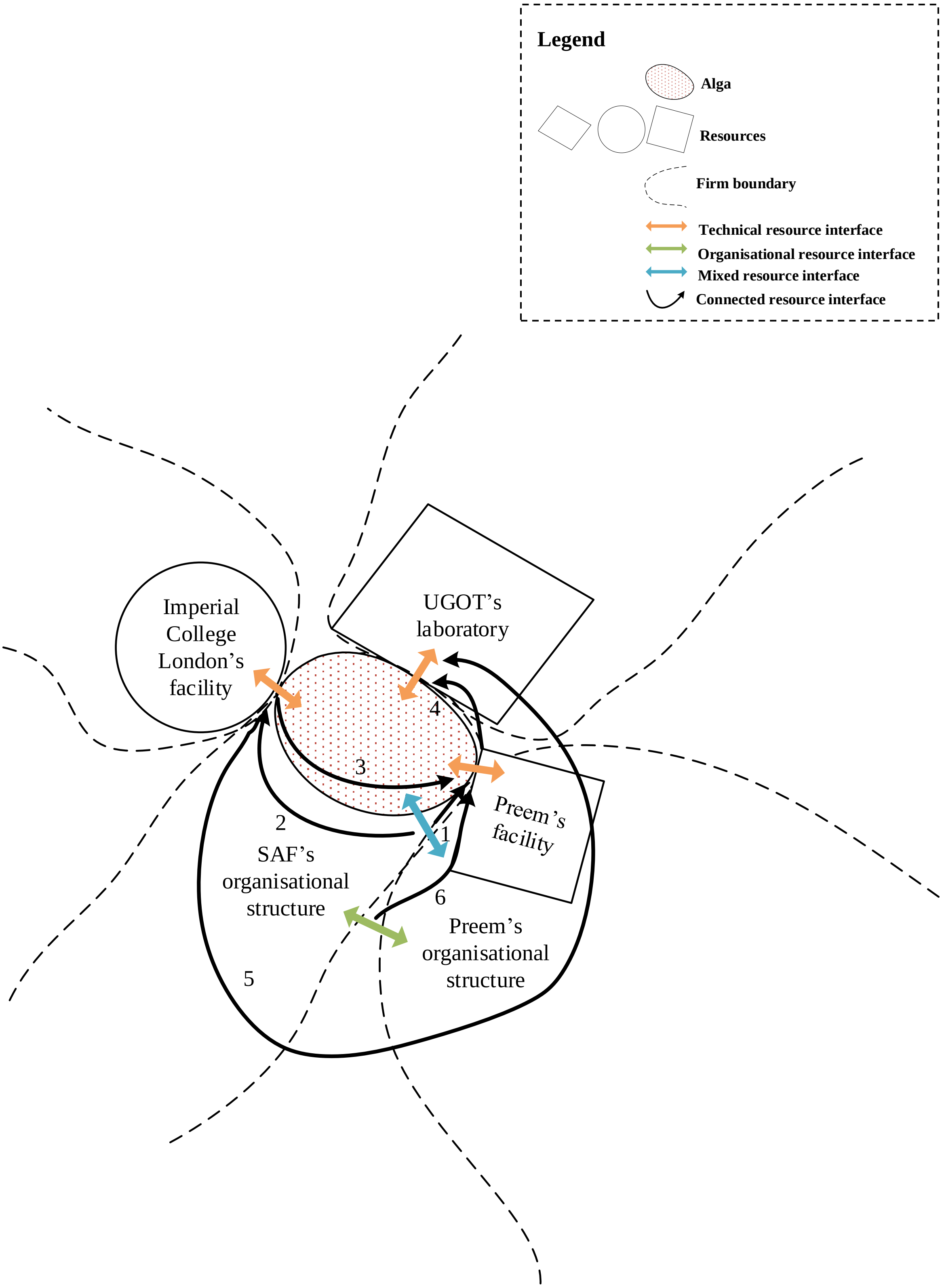


Figure 5. Connected resource interfaces in the resource constellation related to the evaluation of the use of the biomass in Preem's production process

The development process connected to the coating solution for solar panels would not be possible without the creation of the symbiosis in Sotenäs. After realising that the waste water from Renova and the municipality was not suitable for cultivating the algae due to the unstable level of nutrition in the water, SAF turned to the fishing industry. When trying to embed the algae in the resource constellation related to the symbiosis in Sotenäs several different resource interfaces were created.

A critical one was the technical interface between the algae and the fish water. The features of the fish water, such as the level of nutrition, functioned well with the absorption of the algae allowing them to grow at a desirable rate. This interface was dependent on the technical interface between the salmon and the fish water, and the constant emission of substances from the fish. As many of the social resources of SAF and Smögen Lax fit well together in terms of their organisational structures and complementary knowledge and competencies, both parties invested their time in developing a joint demonstration plant. Thus, Smögen Lax saw an opportunity to integrate SAF's algae into the process of cleaning the fish water and consequently let SAF build an algae cultivation plant in the backyard of its facility. Smögen Lax also built a prototype fish farm to which SAF could connect the algae cultivation plant. Hence, the good match between the algae and the fish water together with the well-suited organisational resources enabled a technical interface between the algae and the internal harvesting technique at SAF. SAF was now able to test different ways of harvesting the algae on several shelves stacked on top of each other. The technical interface between the algae and the fish water enabled an evaluation of the biomass to be used as fish fertiliser for the farm and as input in the forthcoming biogas plant. SAF could also harvest silica to test in UGOT's laboratory to evaluate if it could be used in solar cell applications. Thanks to the silica's UV-blocking characteristics and the ability to harvest enough of the material, a technical interface between the algae and the cosmetics company's laboratory was developed to test if the silica could be used in its skin products. This was an important interface that provided SAF with one of its first revenue streams. The technical interface would not have been possible without the organisational interface between SAF and the cosmetics company. The cosmetics company's organisational structure relied on flexible processes and employees who were engaged in development projects and facilitated the use of new products. Hence, it was a good match with SAF's vision.

Moreover, as the aim was to build a symbiosis cluster in Sotenäs that would allow several actors to use each other's waste as input in their production processes, it was important to understand how the fish farm and algae cultivation would eventually be scaled up. The technical interface between Smögen Lax's fish farm and the algae had to be adapted according to how other interfaces could potentially be developed between the algae and future customers. As SAF wanted to sell silica to actors within the solar panel industry it had to produce enough of it to harvest and sell. Thus, the technical interface between the current fish farm and the algae, and the characteristics of the algae, such as their size, led to the idea of locating the algae cultivation on top of the future full-scale fish farm. To realise this, water needed to be pumped upwards to reach the algae cultivation, which resulted in a new feature of the fish farm needing to be developed. Furthermore, there was an opportunity to use the existing infrastructure to remove waste water from the fish farm. A future technical interface that may impact the future full-scale fish farm and the interface between the algae and the fish water could be the interface between Orkla's water pipes and Smögen Lax's fish water.

The technical interface between the algae and UGOT's laboratory revealed the UV-blocking characteristic of the silica. Consequently, in the mixed interface between the algae and SAF's organisational structure, new features were added to the business model, such as developing the idea of integrating the silica into a coating solution for solar panels. However, since the organisational interface between SAF's organisational structure revealed a lack of competence in developing the coating material internally, SAF turned to a coating producer which aimed to sell coating material to solar panel producers. This new technical interface between the algae and the coating producer's facility created tensions in the organisational interface between the different units at SAF and thus resulted in clearer roles between the product development and marketing units. Figure 6 shows the mixed, the four organisational and eleven technical resource interfaces, created when embedding the algae in the resource constellation related to the symbiosis in Sotenäs and the development of the coating solution for solar panels.

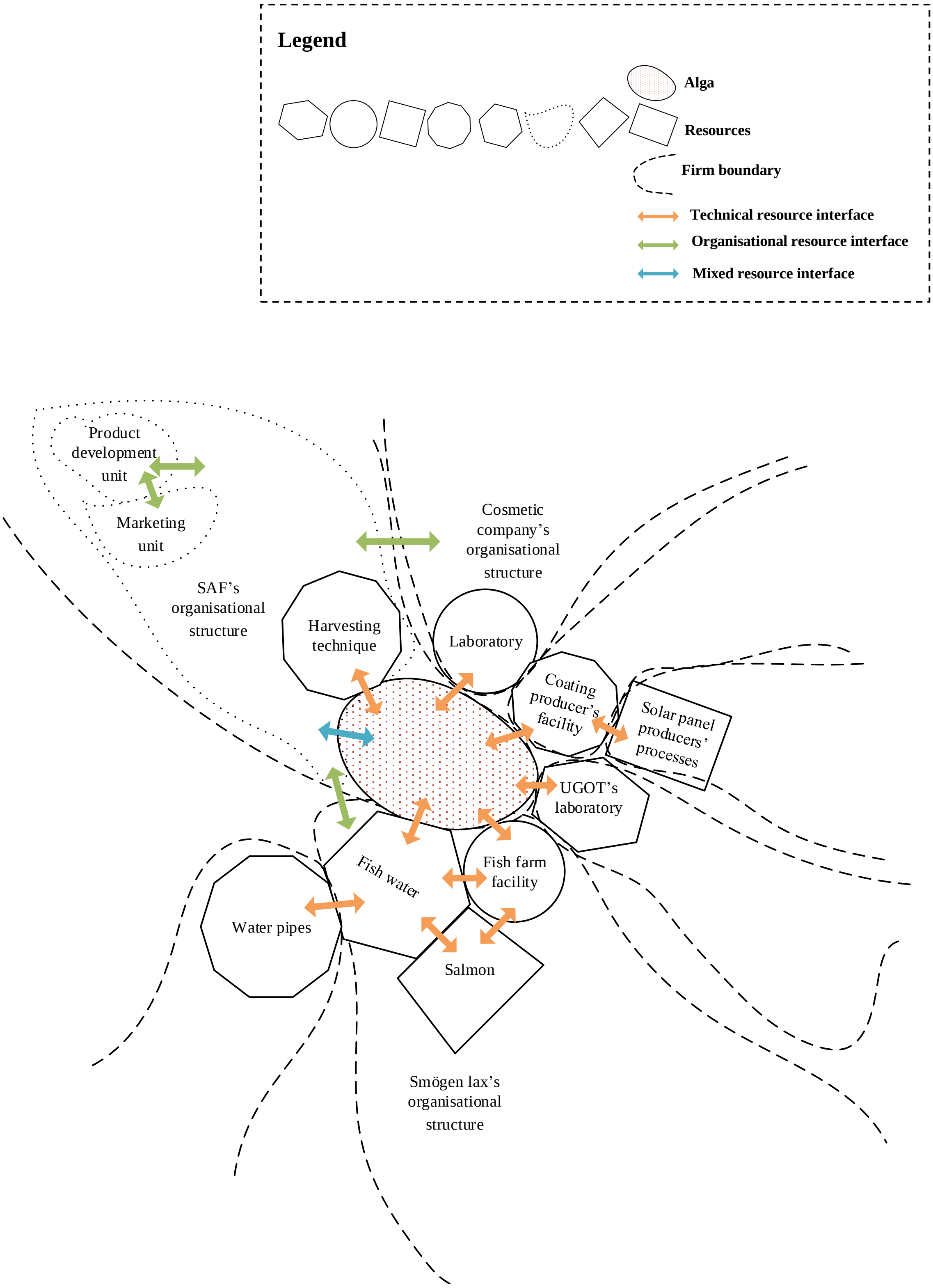


Figure 6. Resource interfaces created when embedding the algae in the resource constellation related to the symbiosis in Sotenäs and the development of the coating solution for solar panels

As seen in Figure 6, several interfaces were and others will potentially be created when developing the symbiosis in Sotenäs. The resource constellation involved in developing the algae cultivation reveals several connected interfaces, as shown in Figure 7. First, there is the technical resource collection interface between the salmon and the fish water that triggered the creation of a new directly connected technical resource tie interface between the fish water and the algae (7). However, this technical resource tie interface would not be possible without the directly connected organisational resource tie interface of SAF's and Smögen Lax's organisational structures (8), and conversely the good technical match between the algae and the fish water triggered new methods of collaboration between the two actors, such as developing the joint demonstration plant (9). Moreover, the functioning technical resource tie interface between the algae and the fish water enabled and triggered adaptations in the directly connected technical resource collection interface between the algae and the harvesting technique (10). When the harvesting technique was able to collect enough silica, it enabled a directly connected technical resource tie between the algae (silica) and UGOT's laboratory to evaluate potential applications for the silica (11). The technical resource collection interface between the harvesting technique and the algae also made it possible to create a directly connected technical resource tie interface between the algae and the cosmetics company's laboratory to evaluate if the silica could be used in skincare products (12). In this case, the good match of organisational resources between the two firms was also important. The organisational resource tie interface between SAF and the cosmetics company's organisational structures enabled SAF's integration into the business processes at the cosmetics company and allowed it to start selling silica for tests to be conducted at the cosmetics company. Consequently, it created prerequisites for the directly connected technical resource tie interface between the algae and the cosmetics company's laboratory (13).

The technical resource tie interface between the algae and UGOT's laboratory also revealed characteristics of the algae in terms of their ability to block UV light. Hence, this created new features in the directly connected mixed resource collection interface between the algae and SAF's organisational structure. SAF wanted to integrate the silica into coating material for solar panels (14). However, the organisational resource collection interface between SAF's organisational structure and product development unit revealed difficulties in proceeding internally with developing the coating material and enabled the indirectly connected technical resource tie interface between the algae and the coating producer's facility (15). This together with the technical resource collection interface between the harvesting technique and the algae enabled a directly connected technical resource tie interface between the algae and the coating producer's facility (16). Hence, the algae's characteristic of blocking UV light made their integration into coating materials that could potentially be sold to solar panel producers an attractive proposition. It was evident from the directly connected technical resource tie interface between the coating producer's facility and the solar panel producer's process that the technical interface between the algae and the coating producer's facility needed to be better adapted (17). Hence, there was still room for improvement and a need for a greater quantity of silica to be produced. As a result, the directly connected technical resource tie interface between the fish farm and the algae needed to be adapted and rebuilt to locate the algae cultivation on top of the fish farm and develop a pump to deliver the fish water to it (18). The technical resource tie interface between the algae and the coating facility also impacted the indirectly connected organisational resource collection interface between the product development unit and the marketing unit at SAF, as clearer roles between the two units had to be developed (19). Furthermore, the technical resource collection interface between the salmon and the fish water indirectly impacted the development of the technical resource collection interface between the harvesting technique and the algae, as it enabled the technical interface between the fish water and the algae (20). It also indirectly enabled the technical resource tie interface between the algae and the coating producer's facility (21).

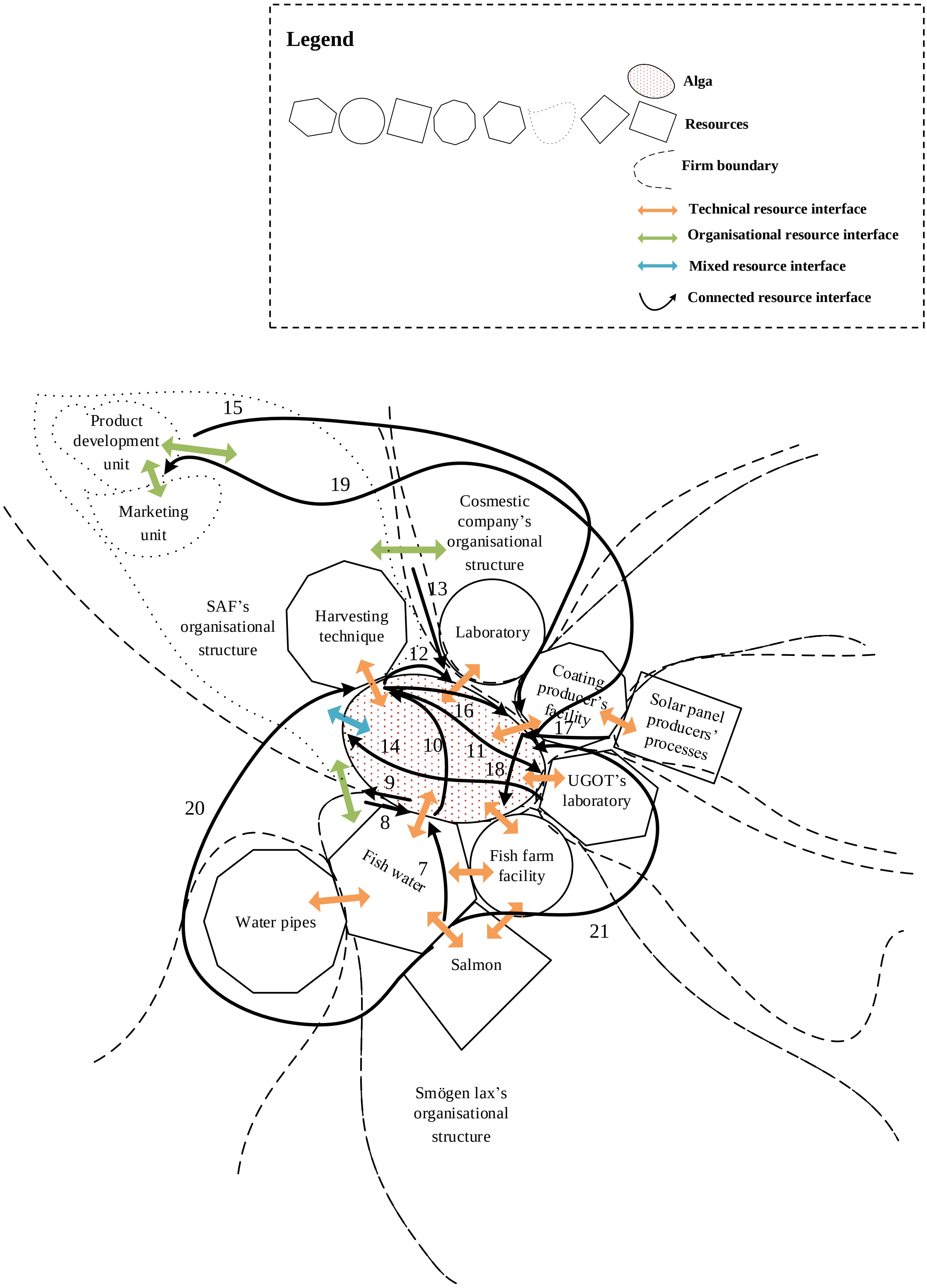


Figure 7. Connected resource interfaces in the resource constellation related to the symbiosis in Sotenäs and the development of the coating solution for solar panels

4.5.2 Resource interaction of Aqua Robur

In the beginning of Aqua Robur’s technological development process, the organisational, technical and mixed resource interfaces were important to understanding how to develop the turbine and its connecting parts. Going from the idea of using the turbine in natural water streams to produce electricity to using it in water pipes to power measurement devices, and today focusing on a complete solution offering including data communication platforms would not have been possible without combining the turbine with other resources within the network. One resource constellation that has been of significant value to understanding how to make the turbine valuable in other actors’ resource collections is the one related to the development of the application connected to extracting electricity at a low level (1-10 kW) in water pipes. The process of embedding the turbine in this resource constellation will be analysed below.

Early in the development process of the turbine, Aqua Robur contacted the company Kretslopp och Vatten (K&V) for input on how to proceed with the application of using the turbine in water pipes in cities (the first-generation prototype). In the organisational resource interface between Aqua Robur’s and K&V’s organisational structures it became clear that Aqua Robur’s idea of providing energy companies with electricity would have to change to investigate instead the possibility of powering measurement devices (the second-generation prototype). This created tensions in the internal organisational interface between Aqua Robur’s organisational structure and the board, as the board was not convinced about giving up on the first idea so easily. An outcome of this was the important technical interface between the turbine and K&V’s water pipes, which enabled data to support the new application. In turn, the new data from the tests together with the common view of the water supply industry, principally that changing existing business relationships and physical infrastructure to enable an innovation such as that of the first application were too costly, convinced the board to support the development of the second-generation prototype. This resulted in Aqua Robur changing its application from an on-grid to an off-grid solution. Instead of selling electricity to energy companies and distributing it through the grid system, the company would now solve the already articulated need by the industry of measuring leakages in the water pipe system. This redefined the mixed interface between Aqua Robur’s organisational structure and the turbine.

Consequently, the internal technical interface between the turbine and the generator had to be developed further with regard to the resource collection at K&V and the development of the internal mixed interface between Aqua Robur’s organisational structure and the turbine. In the technical interface between the turbine and the water in the water pipes at the test plant, it was clear that the turbine extracted too much energy, resulting in the water pressure being too low. To avoid this, the technical interface between the turbine and the generator had to be modified. Hence, the coil in the generator needed to be adapted to avoid extracting too much energy from the water. In the mixed interfaces between the generator and the consultants and the turbine and the consultants, adaptations were made to both the turbine and the generator, e.g. the size of the turbine blades and the technical parameters of the coils, to meet the requirements of K&V. Furthermore, it was important that the technical interface between the generator and the measurement device was aligned. Namely, the measurement device needed enough electricity to be able to measure leakages. Consequently, the technical interface between the generator and the supplier in Kalmar's production facility needed to be adapted to produce the specific coil that the consultants had developed. Figure 8 shows the three mixed, two organisational and five technical resource interfaces that are visible when embedding the turbine in the resource constellation related to the development of the turbine to power measurement devices in water pipes.

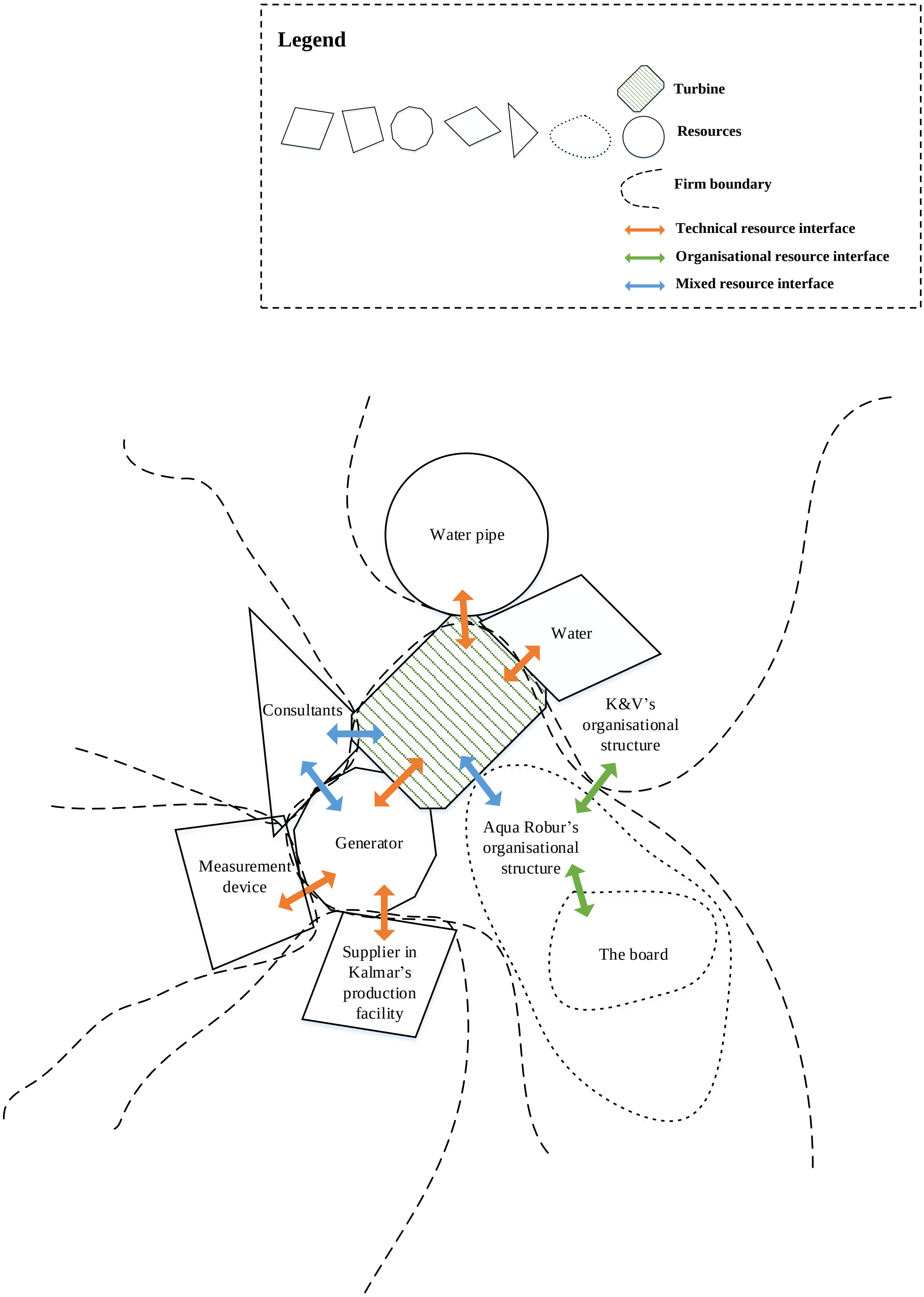


Figure 8. Resource interfaces created when embedding the turbine in the resource constellation related to the development of the turbine to supply electricity to measurement devices in water pipes

There are several connected resource interfaces in the resource constellation in which the turbine is embedded, as seen in Figure 9. One of these is the organisational resource tie interface between K&V's organisational structure and Aqua Robur's organisational structure, which revealed a conflict in the directly connected organisational resource collection interface between Aqua Robur's organisational structure and its board's vision in terms of not sharing the same idea of which application to develop (22). This, in turn, triggered the indirectly connected technical resource tie interface between the turbine and K&V's water pipes (23) as new data were needed to support Aqua Robur in changing the application. The results of the tests at K&V reversely impacted the indirectly connected organisational resource collection interface (24) as the board was provided with evidence to support saying yes to the new application to provide measurement devices with electricity to measure leakages. Hence, the directly connected mixed resource collection interface between Aqua Robur's organisational structure and the turbine was developed, as new features of the turbine were needed to align with Aqua Robur's vision to sell an off-grid solution (25). This, in turn, enabled new tests in the directly connected technical resource tie interface between the turbine and K&V related to drops in water pressure when extracting energy to power the measurement devices (26). The matching of K&V's and Aqua Robur's organisational structures therefore resulted in a new indirectly connected technical resource tie interface between the turbine's generator and the measurement device (27).

Furthermore, the technical resource tie interface between the turbine and the water pipe triggered the directly connected mixed resource tie interface between the turbine and the consultants (28). Letting the turbine interact with the water pipes triggered a change, as a result of the features of the water pipe, in the interface between the turbine and the consultants, resulting in a certain size of turbine and turbine blades. The technical resource tie interface between the water and the turbine revealed that the coil caused critical drops in pressure, which triggered a change in the technical resource collection interface between the turbine and the generator (29). Consequently, this triggered new resource features to be developed in the mixed resource tie interface between the generator and the consultants, such as developing a coil that could extract the required level of energy from the water stream (30). However, the mixed resource tie interface between the generator and the consultants was also adapted with regard to the technical resource tie interface between the measurement device and the generator, as the measurement device needed a certain amount of electricity to measure leakages. Thus, the technical resource tie interface between the generator and the measurement device impacted the directly connected mixed resource tie interface between the consultants and the generator (31). In turn, the mixed resource tie interface between the consultants and the generator triggered the directly connected technical resource tie interface between the production facility of the supplier in Kalmar and the generator to adapt the production of the coils in Kalmar (32). Consequently, there is an indirect connection between the technical resource tie interface of the measurement device and the generator, and the technical resource tie interface of the production facility in Kalmar and the generator, via the mixed resource tie interface between the consultants and the generator (33).

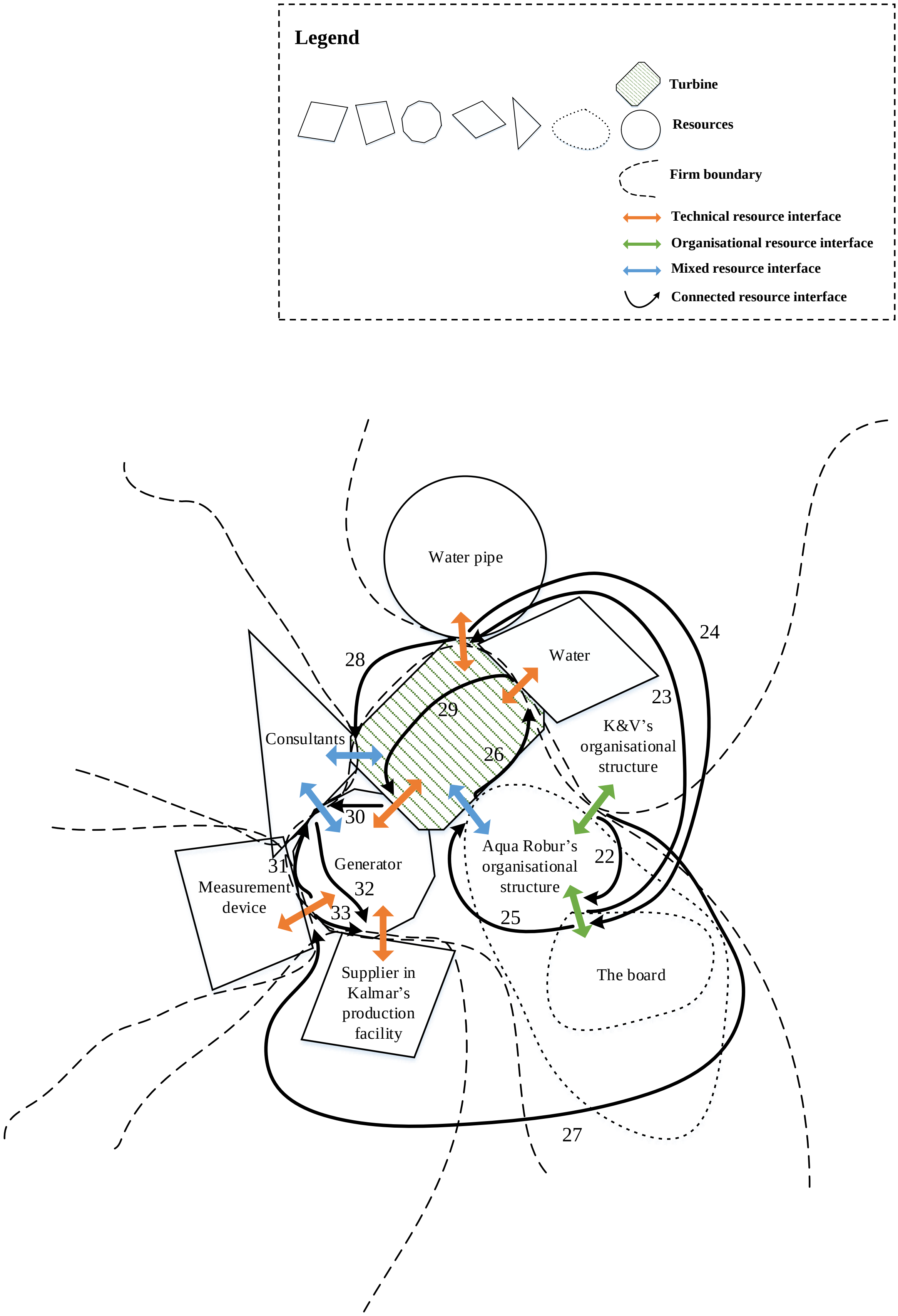


Figure 9. Connected resource interfaces in the resource constellation related to the development of the turbine to supply electricity to measurement devices in water pipes

4.5.3 Resource interaction of Modvion

Modvion has worked with several actors to develop its wind power tower from wood. To build a 150-metre tall tower in wood is a challenge due to the characteristics of the material and external factors such as weather and loads. Hence, a first step was to build a prototype to develop and assess the characteristics of the material, the tower's structural design and the coating protection. Furthermore, as the tower should be able to be delivered in modules, additional focus was put on the process of developing an assembly method and specific joint solutions to facilitate the smooth assembly of the tower at the future wind parks. Several actors' resource collections were involved in developing the prototype. The process of embedding the tower in the resource constellation related to the development of the wind power tower from wood will be analysed below.

One resource interface that has played a significant role in the development of the wood tower is the mixed interface between the wind power industry's organisational structure and the tower. Modvion and its inventor were aware, early in the development process of the tower, of the general trend in the wind power industry towards taller and larger wind turbines to extract more energy with lower production and environmental costs. Hence, the tower should not only be produced from wood, as it is an environmentally friendly material, but also be tall enough and transportable on the roads. By combining the tower with RISE's laboratory and its computer programs and digitally simulating putting the nacelle on top of the tower, the technical resource interface between the tower and the facility revealed the potential resonance. The mixed interface between the tower and the master's thesis students also helped shape the parameters of the tower, such as the optimal diameter and number of Laminated Veener Lumber (LVL) layers. The mixed interface revealed that rather than a diameter of 11.5 metres, according to Modvion's initial idea, the tower's diameter should be changed to 12.5 metres and the number of LVL layers increased from three to five. It was also clear in the mixed interface between the tower and the master's thesis students that two types of joining solutions needed to be combined to withstand external factors such as the weather, loads and wind and to facilitate easy assembly. The joining solutions, in turn, were tested in fatigue tests at RISE.

The organisational resource interface between Modvion's organisational structure, in terms of creating a sustainable wood tower, and Moelven's knowledge on how to produce wood products revealed a shared idea of using a specific wood material to build large towers. As Moelven saw the value in letting Modvion use its production facility, a new technical resource interface was created between it and the tower. This was crucial since it enabled Modvion to produce the components developed by the master's thesis students, its employees and RISE. Several adaptations were made to the technical interface of Moelven's production facility such as adding an extra production line next to the original ones and assigning some staff to work specifically on producing Modvion's components. Hence, new working routines were developed in the mixed resource interface between the production facility and the employees at Moelven. Moreover, the technical interface between Moelven's production facility and that of the wood supplier was important in enabling the production of specific wood products that Moelven was not able to produce. Figure 10 below shows the three technical resource interfaces, three mixed resource interfaces and one organisational resource interface visible when embedding the tower in the resource constellation related to the development of the wind power tower from wood.

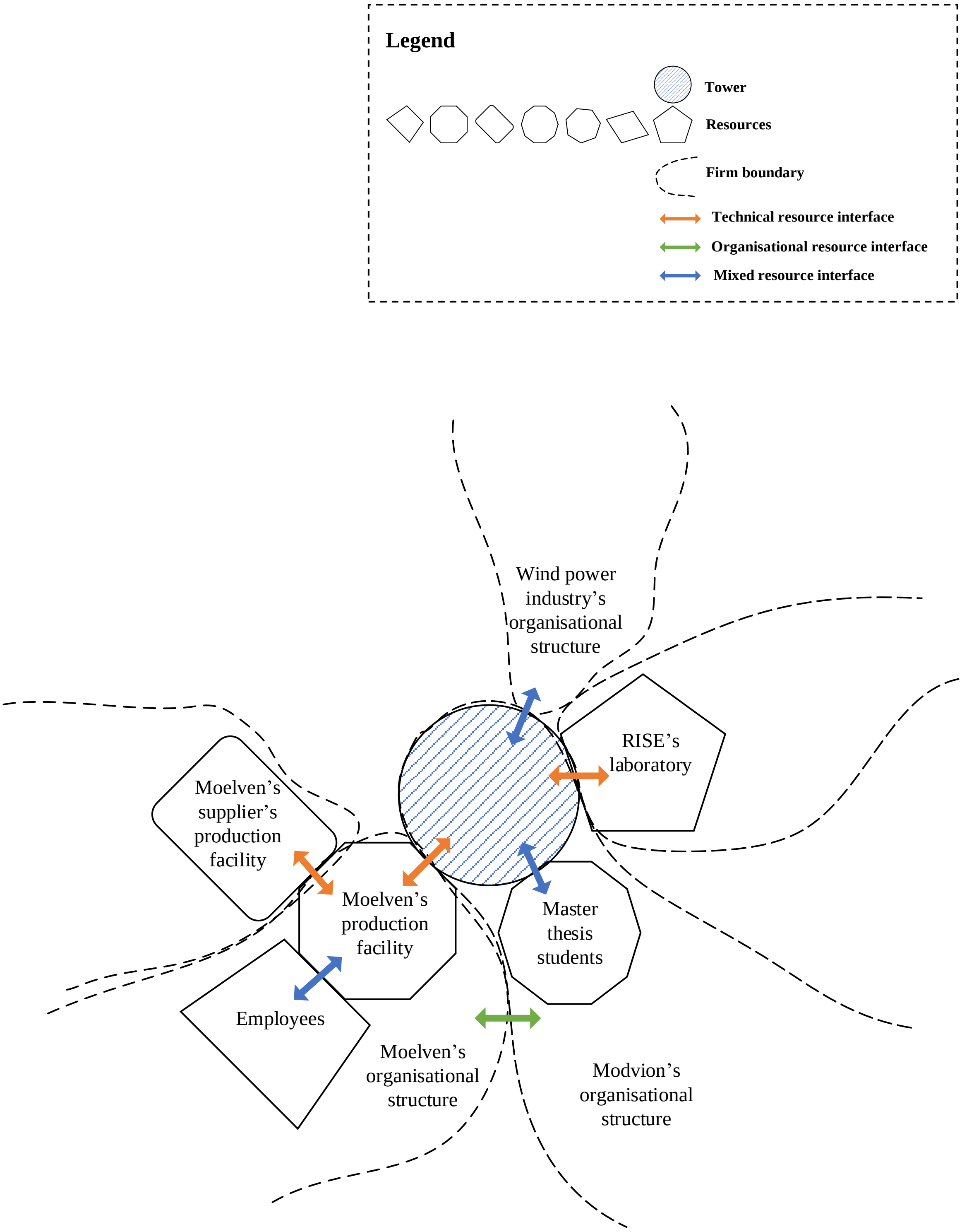


Figure 10. Resource interfaces created when embedding the tower into the resource constellation related to the development of the wind power tower from wood

Several different interfaces were created when trying to embed the tower in the resource constellation related to the development of the wind power tower from wood. As seen in Figure 11, each of the interfaces has a connection to another interface in the specific constellation. First, the mixed resource tie interface between the wind power industry's organisational structure and the tower impacted the directly connected technical resource tie interface between the tower and RISE's laboratory in terms of how the calculations were carried out in the computer programs regarding certain parameters, such as the height of the tower (34). The mixed resource tie interface also impacted the directly connected mixed resource collection interface between the tower and the master's thesis students since the wind power industry's specific requirements on height influenced how the master's thesis students developed the size and joints of the tower (35). In turn, the mixed resource collection interface between the tower and the master's thesis students developed the directly connected technical resource tie interface between the tower and RISE's laboratory, as the joints could now be submitted to fatigue tests (36).

Even though the technical resource tie interface between the tower and Moelven's production facility was not well adapted at first, as was pointed out by the master's thesis students, the organisational resource tie interface between Modvion's organisational structure and Moelven's knowledge impacted the directly connected technical resource tie interface between the tower and Moelven's production facility (37). Moelven was open to adapting the features of its production facility, including adding an extra production line to meet the requirements of Modvion's calculations. Specifically, the technical resource tie interface between RISE's laboratory and the tower impacted the directly connected technical resource tie interface between the tower and Moelven's production facility (38). Additionally, the mixed resource collection interface between the tower and the master's thesis students impacted the directly connected technical resource tie interface between the tower and Moelven's production facility (39). This technical resource tie interface in turn enabled adaptations in the directly connected mixed resource collection interface between Moelven's production facility and its employees. For example, a group of employees was specifically assigned to work on producing the wood material to be used in Modvion's tower (40). Hence, there was an indirect connection between the resource collection interface of the tower and the master's thesis students, and the mixed resource collection interface of Moelven's production facility and its employees (41). Moreover, the technical resource tie interface between the tower and Moelven's production facility impacted the directly connected technical resource tie interface between Moelven's production facility and that of the wood supplier (42).

Not only were directly connected resource interfaces seen but so were indirectly connected ones. One example is the mixed resource tie interface between the wind power industry's organisational structure and the tower, which enabled the specific adaptations in the indirectly connected mixed resource collection interface between Moelven's production facility and its employees via the mixed resource collection interface between the tower and the master's thesis students, and thereafter the technical resource tie interface between the tower and Moelven's production facility (43). Another example is the mixed resource collection interface between the master's thesis students and the tower that indirectly impacted the technical resource tie interface between Moelven's production facility and that of its supplier via the technical resource tie interface between the tower and Moelven's production facility (44). Moreover, the adaptations of the technical resource tie interface between the tower and RISE's laboratory also indirectly impacted the technical resource tie interface between Moelven's production facility and that of its supplier via the technical resource tie interface between the tower and Moelven's production facility (45).

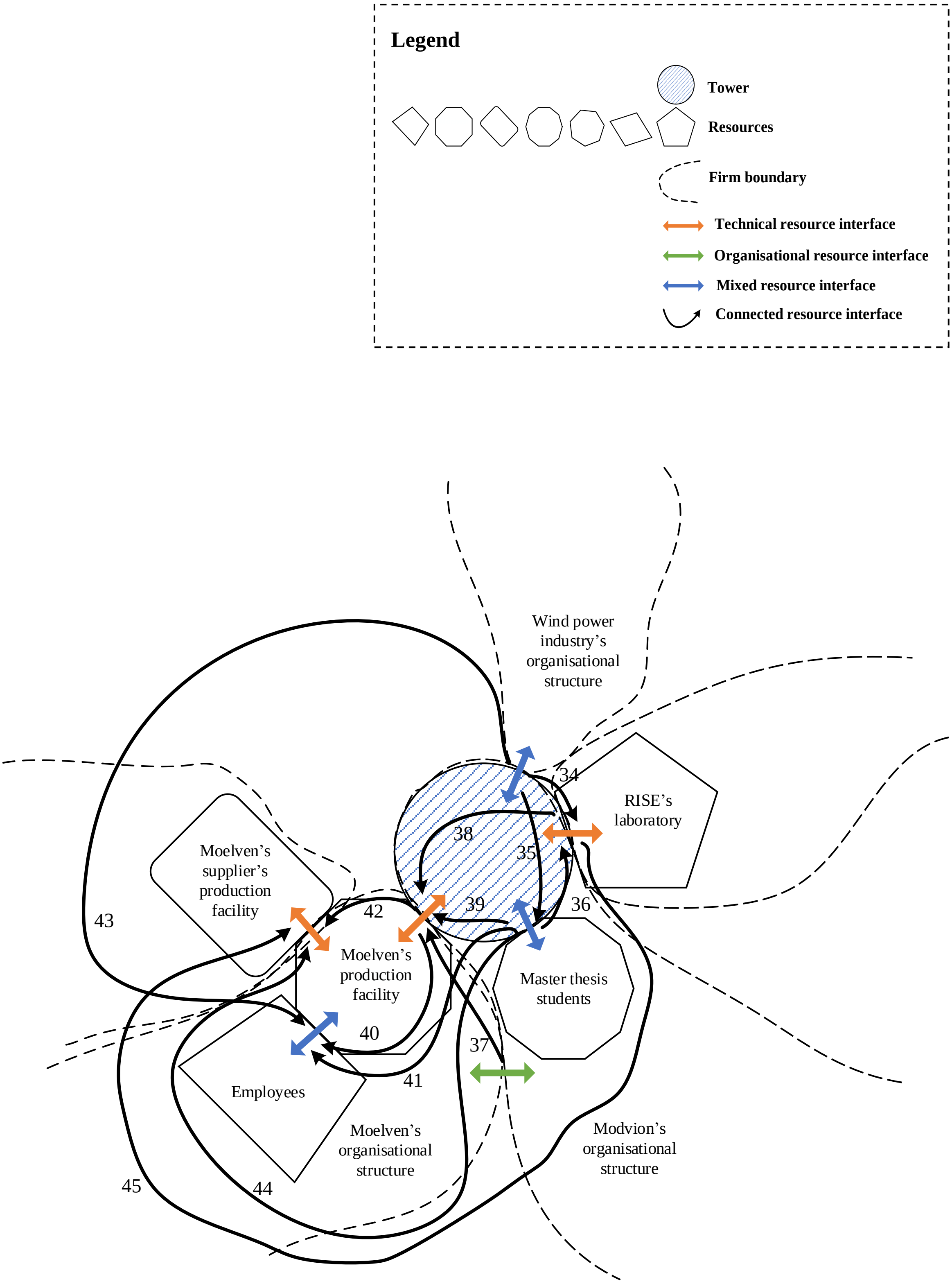


Figure 11. Connected resource interfaces in the resource constellation related to the development of the wind power tower from wood

4.6 Analysis of connected resource interfaces

As seen in the above analysis, a variety of different connections between resource interfaces are necessary to embed resources in different resource constellations and thus create new and useful resources. By taking the starting point in a certain resource interface belonging to either *a resource collection* or a *resource tie* between two actors, it is possible to analyse how this resource interface triggers changes, or even enables or disables directly and indirectly connected resource interfaces. Table 8 shows the 45 connected resource interfaces identified in the analysis of the three start-ups' resource interactions in the business network that will act as a basis for the analysis in this section.

4.6.1 The eight categories of connected resource interfaces

The subcase analysis revealed examples of connected interfaces within each of the eight categories demonstrated in the analytical model; see Figure 2 and table 1 in section 2.4. The first category (square i) in Table 8 identifies one example of how a resource collection interface within a resource collection in a firm may trigger a change in a directly connected resource interface within the same resource collection in the firm. This was the organisational resource collection interface between Aqua Robur's organisational structure and the board which impacted the mixed resource collection interface between Aqua Robur's organisational structure and the turbine (25).

When it comes to how a resource collection interface may trigger a change in a directly connected resource tie interface (ii), several examples were identified. An example of how a connection between a technical resource collection interface and a technical resource tie interface may look is provided by the technical resource collection interface between Smögen Lax's salmon and the fish water that enabled another technical resource tie interface between the fish water and SAF's algae (7). Another example is the mixed resource collection interface between Aqua Robur's organisational structure and the turbine that triggered a change in the technical resource tie interface between the turbine and the water in K&V's pipes (26), or the mixed resource collection interface between Modvion's tower and the master's thesis students that impacted the directly connected technical resource tie interface between the tower and Moelven's production facility (39). Moreover, there was a technical resource collection interface between Aqua Robur's turbine and the generator that triggered a change in the mixed resource tie interface between the generator and the consultants in terms of developing new features for the generator (30).

One example of a resource collection interface that impacts indirectly connected resource collection interfaces (iii) and has at least one interface between was identified in the embedding of the algae in the resource constellation related to the symbiosis in Sotenäs. The technical resource collection interface between the salmon and the fish water at Smögen Lax impacted the technical resource collection interface between the algae and the harvesting technique at SAF (20) in terms of ensuring the required growth rate of the algae and adapting the harvesting technique according to the level of growth.

Furthermore, several examples of how a resource collection interface impacts an indirectly connected resource tie interface (iv) were identified in the previous analysis. One example was how an organisational resource collection interface impacts a technical resource tie interface, as in the interaction between Aqua Robur's organisational structure and its board triggering the technical resource tie interface between the turbine and K&V's water pipes (23). Another was how a technical resource collection interface impacts a technical resource tie interface, as in the interaction between Smögen Lax's salmon and fish water and its impact on the interaction between the algae and the coating producer's facility (21). Additionally, there was a mixed resource collection interface between the master's thesis students and the tower that impacted the indirectly connected technical resource tie interface between Moelven's production facility and that of its supplier in terms of buying new types of wood products at Modvion's request.

A closer look at the analysis of the category of resource tie interfaces and their impact on both directly and indirectly connected resource interfaces revealed several examples of how a resource tie interface impacts a directly connected resource collection interface (v). One example is the organisational resource tie interface between K&V's and Aqua Robur's organisational structures, which led to friction in the organisational resource collection interface between Aqua Robur's organisational structure and the board (22). Moreover, there was a technical resource tie interface between the algae and the fish water, which, thanks to its working interface, enabled and triggered adaptations in the directly connected technical resource collection interface between the algae and the harvesting technique (10). Additionally, the analysis revealed the impact of a technical resource tie interface between the tower and Moelven's production facility on the mixed resource collection interface between Moelven's production facility and its employees (40). The employees were assigned to work mainly on the production of the tower. Finally, there was the mixed resource tie interface between the wind power industry's organisational structure and the tower, which impacted the mixed resource collection interface between the tower and the master's thesis students (35).

The analysis of the start-ups' resource interaction showed several examples of the impact of a resource tie on a directly connected resource tie (vi). One example was the organisational resource tie interface between SAF's and Preem's organisational structures. Preem's policy of only collaborating with start-ups that can show potential to scale up their operations made a collaboration with SAF difficult to continue beyond a certain point in time. Consequently, the technical resource tie interface between the algae and Preem's facility dissolved (6). Moreover, the technical resource tie interface between the algae and the fish water enabled new ways for SAF and Smögen Lax to collaborate, including developing a joint demonstration plant in Sotenäs (9). Several examples of how technical resource tie interfaces impact other directly connected technical resource tie interfaces were identified through the analysis. One example was the technical resource tie interface between Modvion's tower and RISE's laboratory, which impacted the development of the technical resource tie interface between the tower and Moelven's production facility (38). The analysis also showed an example of how a technical resource tie interface impacts a mixed resource tie interface. The interface between Aqua Robur's turbine and the water pipe revealed features that made the directly connected interface between the consultants and the turbine change in response to the need to change the size of the turbine (28). A final example in this category is the mixed resource tie interface between the algae and Preem's organisational structure, which at first worked out well since both actors shared the idea of moving towards sustainable fuel production, which in turn enabled the early technical resource tie interface between the algae and Preem's facility (1).

With regard to how a resource tie interface impacts an indirectly connected resource collection interface (vii), one example is the technical resource tie interface between the algae and the coating producer's facility, which triggered a change in the organisational resource collection interface between SAF's product development and marketing units (19). Furthermore, there was a mixed resource tie interface between the wind power industry's organisational structure and Modvion's tower which impacted the indirectly connected mixed resource collection interface between Moelven's production facility and its employees (43).

In the final category, the analysis showed two examples of the impact of a resource tie interface on an indirectly connected resource tie interface (viii). Firstly, the organisational resource tie interface between Aqua Robur and K&V's organisational structures revealed the need for Aqua Robur to change its application area to provide electricity to measurement devices. This resulted in an indirectly connected technical resource tie interface between the turbine's generator and the measurement device (27). Moreover, a technical resource tie interface was established between the algae and Imperial College London's facility, which triggered a change in the indirectly connected technical resource tie interface between the algae and UGOT's laboratory (5) as it was revealed that the algae resulted in a composition of bio-crude oil that UGOT needed to find a way to change.

Table 8. The various types of connected resource interfaces created when embedding resources in the business network

		Directly connected resource collection interface			**Directly connected resource tie interface**			**Indirectly connected interface (At least one resource interface between)**					
								A resource collection interface			**A resource tie interface**		
		Org.	Techn.	Mix.	Org.	Techn.	Mix.	Org.	Techn.	Mix.	Org.	Techn.	Mix.
A resource collection interface	Org.			**(25)**								**(15) (23)**	
	Techn.					**(7) (11) (12) (16)**	**(30)**		**(20)**			**(21)**	
	Mix.	(i)			(ii)	**(39) (36) (26)**		(iii)		**(41)**	(iv)	**(44)**	
A resource tie interface	Org.	**(22)**				**(6) (8) (13) (37)**						**(27)**	
	Techn.		**(10) (29)**	**(14) (40)**	**(9)**	**(3)(4) (17) (18) (38) (42)**	**(28) (31)**	**(19) (24)**				**(5) (33) (45)**	
	Mix.	(v)		**(35)**	(vi)	**(1) (2) (32) (34)**		(vii)		**(43)**	(viii)		

4.7 Towards patterns of resource interaction: the connected resource interfaces and their network effects

Having considered the different types of connected resource interfaces, it is now of interest to look further into the different patterns of resource interaction observed in the previous analysis. Hence, this section will answer the first research question: How are resource interaction patterns related to connected resource interfaces? In this analysis, a pattern is described as a sequence of connections necessary for (or a result of) embedding a focal resource in a resource constellation. In many cases, this is related to the categories of indirectly connected resource interfaces since it involves at least two connections with one interface between them. However, it can also relate to directly connected resource interfaces, as several direct connections in parallel may lead to a specific resource interface, or specific direct connections may result in several other connections.

Five different patterns of resource interaction are identified and described below. Their starting points are either a resource collection interface or a resource tie interface. The first two concern directly connected resource interfaces and the next three indirectly connected resource interfaces.

4.7.1 Patterns of directly connected resource interfaces

The following two resource interaction patterns concern the effect of a resource interface on a directly connected resource interface.

'The technical resource tie interface and its effect on a directly connected resource collection interface'

The first type of resource interaction pattern is related to directly connected resource interfaces, the first example of which is the effect of a technical resource tie interface on a directly connected resource collection interface, as seen in Figure 12. Many of the directly connected resource interfaces that both trigger and are subject to changes in other directly connected resource interfaces belong to the group of resource tie interfaces. The previous analysis shows the importance of adapting the interfaces not only within the firm's own resource collection but also between those of other firms. As seen in the previous analysis, technical resource tie interfaces play an important role in embedding the three focal resources in specific resource constellations. There are technical interfaces between two actors that trigger changes in mixed resource collection interfaces, between the focal technical resource and internal organisational resources, and technical resource collection interfaces between two technical resources.

One illustrative example is the technical resource tie interface between the algae and UGOT's laboratory, which showed, through optical studies, that the silica surrounding the algae redistributes UV light and consequently prevents it from reaching the DNA of the cells. Later, this newly discovered characteristic was the catalyst for new features in the mixed resource collection interface between the algae and SAF's organisational structure. SAF had the idea of developing and producing its own coating material for solar panels. However, this idea could not be realised in the activated resource structure at SAF since the start-up had neither previous experience nor knowledge of being an actor in the solar panel industry. Instead, SAF had to turn to coating producers to develop a good material. Another example of how a technical resource tie interface can impact a mixed resource collection interface is the technical resource tie interface between the wood tower and Moelven's production facility and its effect on the mixed resource collection interface between Moelven's production facility and its employees. In order to produce the engineered wood material to build the tower, Moelven had to change its production layout and make room for an extra production line. This change in turn affected the organisational resource of Moelven's employees, as some of them had to be relocated to Modvion's assigned production line.

Furthermore, a technical resource tie interface may also affect a technical resource collection interface. One example is the technical resource tie interface between the turbine and the water at K&V, in which certain requirements, such as a minimum level of water pressure in the pipes, impacted the development of the turbine generator. In the interface between the water and the turbine it became evident that too much energy was being extracted from the water, thus creating too great drop in pressure. Consequently, this affected the directly connected technical resource collection interface between the turbine and the generator since technical parameters, such as the coil, needed to be adapted in order to maintain the required level of pressure. Another example is the technical resource tie interface between the algae and the fish water at Smögen Lax in which the stable level of nutrition from the salmon enabled a technical resource collection interface between the algae and the harvesting technique. In this case, it facilitated a demonstration plant where SAF could develop the harvesting technique in symbiosis with growing algae and cleaning waste water. The examples of 'the effect of a technical resource tie interface on a directly connected resource collection interface' show how a technical resource tie interface is directly connected to a resource collection interface (square v in Table 8).

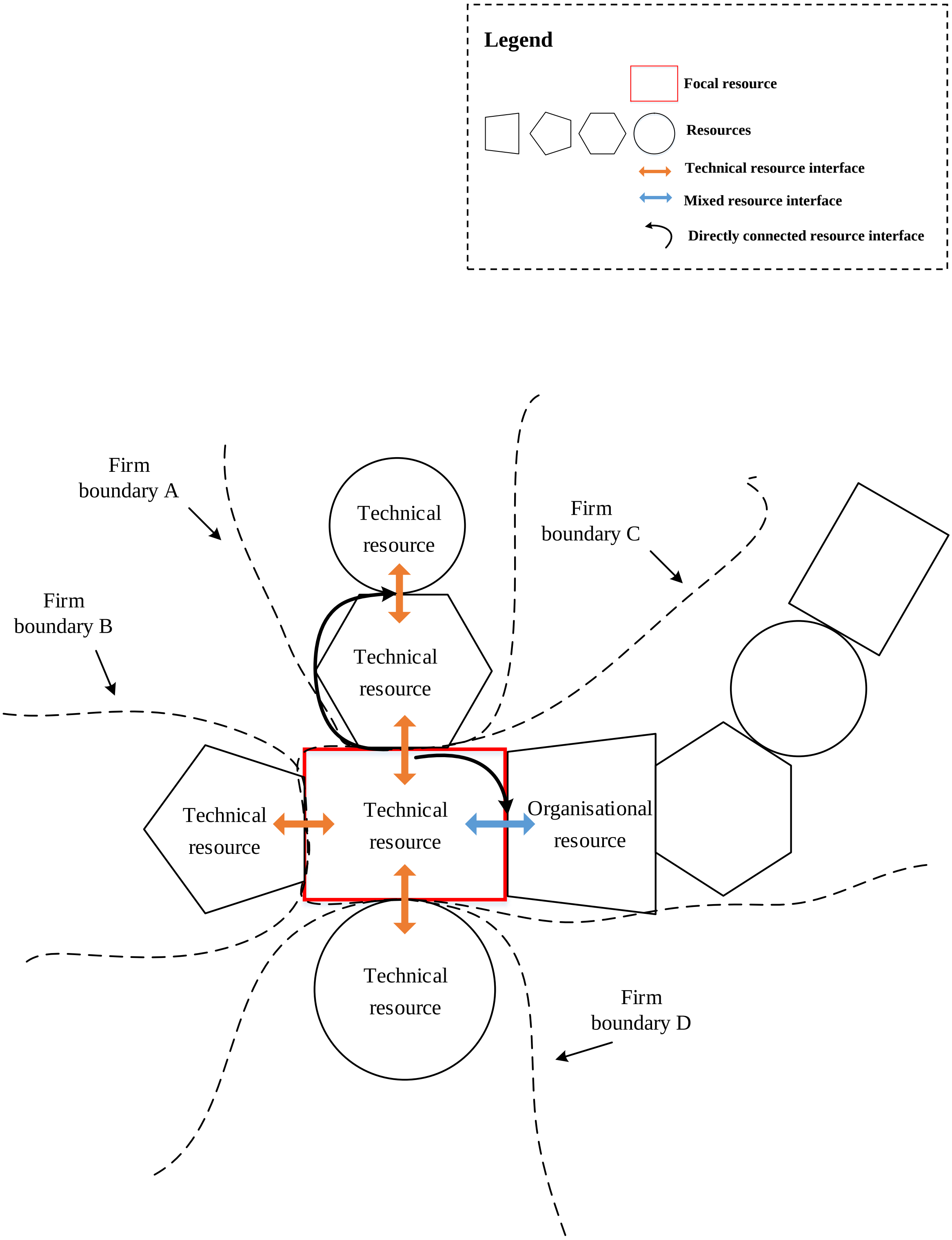


Figure 12. The effect of a technical resource tie interface on a directly connected resource collection interface

‘The interplay between resource interfaces and its effect on a directly connected resource tie interface’

The second type of resource interaction pattern related to the direct connection between resource interfaces concerns the interplay between technical and organisational resource interfaces. As seen in Table 8, most of the identified resource interfaces that triggered a change in a connected resource interface belong to the technical resource tie interfaces group. Furthermore, it is evident that most of the interfaces that were subject to change belong to the technical resource tie interfaces group. Even though the technical interfaces dominate in the three start-ups’ resource interactions, as they are developing technical products, it is relevant to acknowledge the role of the organisational resources and their interfaces. Hence, the interplay between technical and organisational interfaces is an important pattern of resource interaction in enabling technical resource interfaces and consequently technological development of products, as illustrated in Figure 13.

Organisational interfaces that have enabled technological development are visible in the technological development processes of all three start-ups. In SAF’s case, many of its social resources fit well with those of Smögen Lax. Their organisational structures and complementary knowledge and competences enabled a technical resource interface between the algae and the fish water. As the activated resource structure at Smögen Lax was already such that it could easily embrace the idea of using algae as a way of cleaning fish water, the crucial technical resource tie interface between the two could be developed. It was a result of the interplay between the organisational resource tie interface and the technical resource collection interface between the fish water and the salmon that helped to develop the technical resource tie interface between the algae and the fish water. When the technical resource tie interface worked well, it in turn enabled the cultivation and harvest of the algae in a sufficient volume to sell to customers. Moreover, this resource interface, together with the organisational resource tie interface between the organisational structures of the cosmetics company, which allowed it to assign a group of employees to deal with product development projects, and SAF enabled the technical resource tie interface between the algae and the cosmetics company’s laboratory and provided SAF’s first revenue stream.

Another example is the organisational resource tie interface resulting from the organisational structures of Aqua Robur and K&V, which helped inform Aqua Robur of which type of application to focus on and created tensions in the organisational resource collection interface between Aqua Robur’s organisational structure and the board. These organisational resource combinations were necessary to enable the technical resource tie interface between the turbine and the water pipes, and later the development of the new application of generating electricity for measurement devices. In the case of Modvion, it was also necessary for the organisational resource tie interface between Moelven’s and

Modvion's organisational structures to work well, as this enabled the technical resource tie interface between the tower and Moelven's production facility. However, the activated resource structure was not formed in a way that allowed the tower to be easily embedded in the production facility, and consequently in the technical resource tie interface between the tower and Moelven's production facility new features, such as an extra production line at Moelven, had to be developed. However, organisational resource interfaces can also hinder technological development as in the case of the organisational interface between SAF's and Preem's organisational structures. While the technical interface between SAF and Preem's refinery worked well, Preem needed to see proof that SAF was able to produce a greater volume of biomass. The previous examples of 'the interplay between technical and organisational resource interfaces' shows how a resource tie interface directly connects to another resource tie interface (vi) and how a resource collection interface directly connects to a resource tie interface (ii).

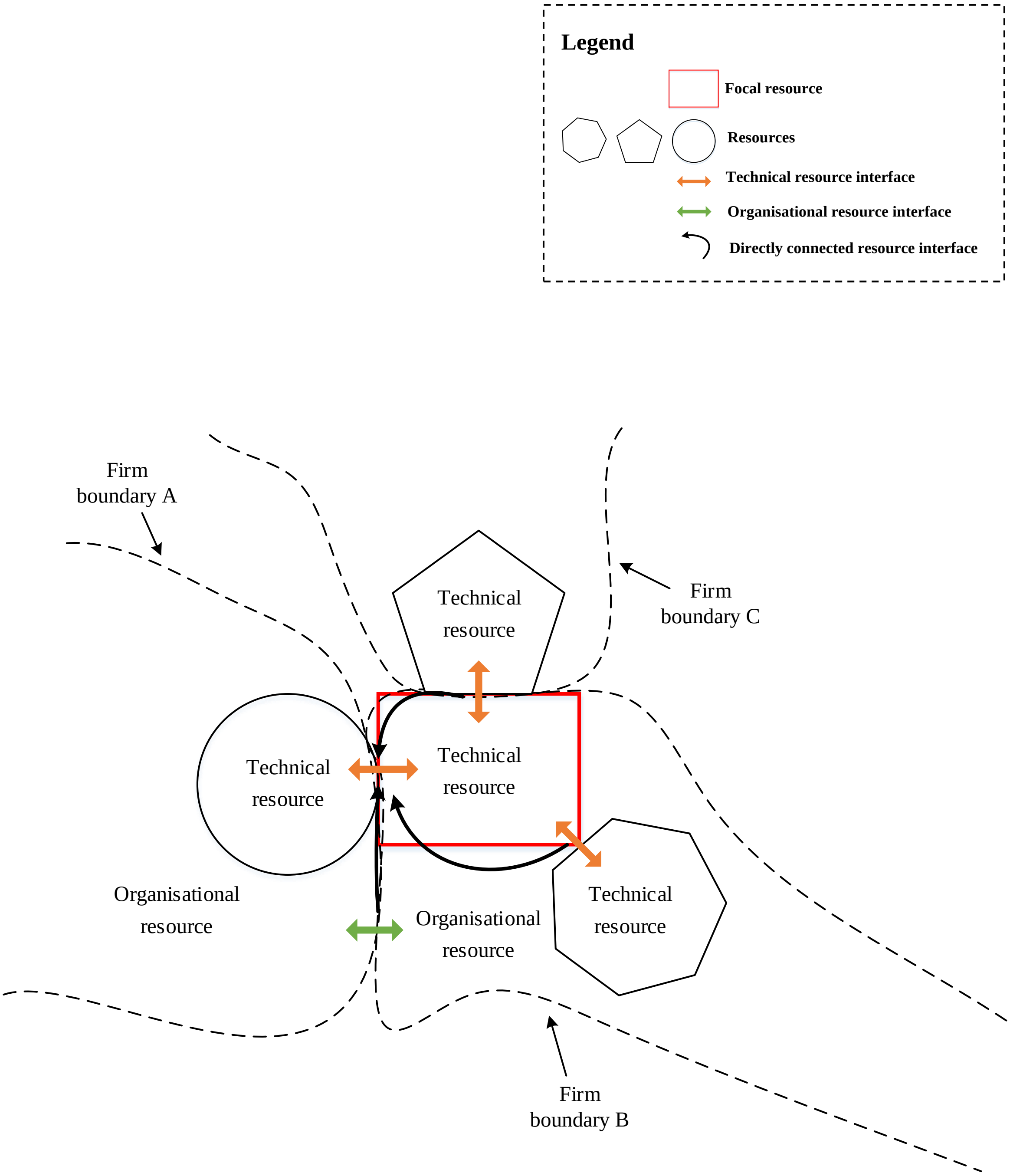


Figure 13. The interplay between technical and organisational resource interfaces

4.7.2 Patterns of indirectly connected resource interfaces

The following three resource interaction patterns concern the effect of a resource interface on an indirectly connected resource interface with at least one interface between them. The impact of a resource interface on an indirectly connected resource interface can hypothetically only involve the resource collection of one or two firms. However, as seen in the previous analysis, embedding a focal resource may also affect other actors outside the dyadic relationship. It is therefore of interest to analyse how a resource interface may affect other actors in the business network and thus create a network effect.

'A resource collection interface and its effect on an indirectly connected resource collection interface'

The third type of resource interaction pattern is shown in Figure 14. It deals with the network effect of a resource collection interface and is exemplified by the impact of one resource collection interface on another via a third resource interface (iii). One example is the process of embedding the algae in the resource constellation related to the symbiosis in Sotenäs and the development of the harvesting technique. The technical resource collection interface between the salmon and the fish water at Smögen Lax was necessary to enable a functioning technical resource tie interface between the algae and the fish water, as the salmon enabled a stable level of nutrition in the water on which the algae could feed. In turn, this enabled a technical resource collection interface between the algae and the harvesting technique as the algae could grow at a stable rate and thus be suitable for harvesting. The ability to harvest enough silica was a prerequisite for creating the technical resource tie interface between the algae and UGOT's laboratory, which resulted in the discovery of the UV-blocking characteristics. In this case, indirectly connected resource collection interfaces existed between two actors but also affected a third: UGOT. Another example is the master's thesis students' calculations for the parameters of the tower that affected the resource collection interface between Moelven's facility and its employees, as it required some of its staff to relocate to the newly built production line. The reason for this was to meet the requirements for the engineered wood to withstand pressure from the nacelle and external weather conditions in line with the students' calculations.

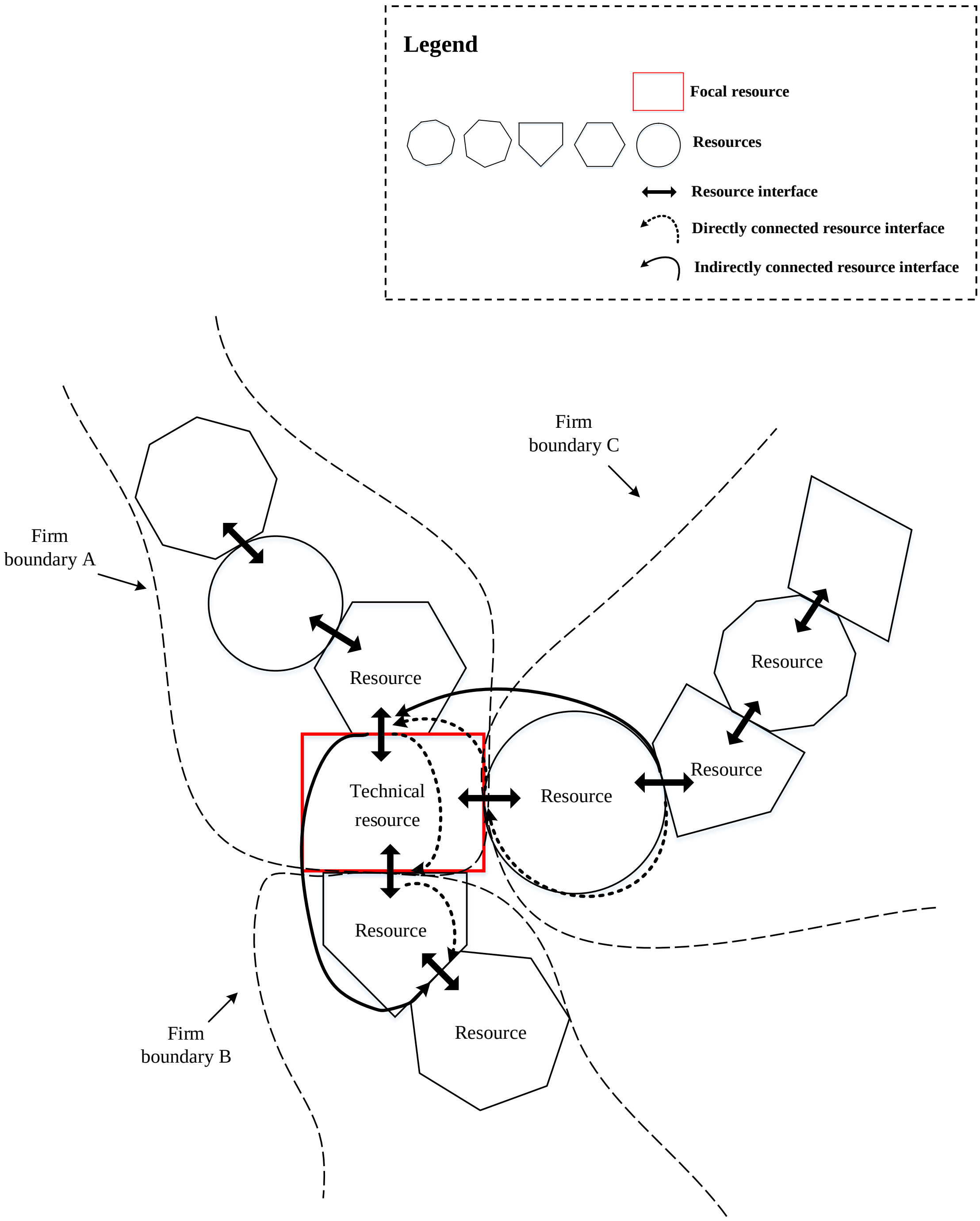


Figure 14. The network effect of a resource collection interface

‘A technical resource tie interface and its effect on an indirectly connected resource tie interface’

The fourth type of resource interaction pattern is shown in Figure 15. It shows the network effect of a technical resource tie interface and, specifically, how two technical resource tie interfaces connect indirectly via a third technical resource tie interface (viii). Two examples were found in the previous analysis. Firstly, the process of embedding the algae in the resource constellation related to the evaluation of using the biomass in Preem’s production process. In the technical resource tie interface between the algae and the facility at Imperial College London, it was revealed that the composition of the bio-crude oil directly impacted the technical resource tie interface between the algae and Preem’s refinery as a result of its nitrogen level being too low. In turn, this impacted the technical resource tie interface between the algae and UGOT’s laboratory, as UGOT had to develop ways to remove the nitrogen. Consequently, four actors were involved in embedding the technical resource in the resource constellation and had to change features of their resources. Secondly, the example of the process of embedding the tower in the resource constellation related to the development of the wind power tower from wood. The technical resource tie interface between the tower and RISE’s laboratory ensured that the calculations made by the master’s thesis students, with regard to the proposed design and material selection, were correct, for example, by submitting the joints to fatigue tests. This in turn impacted the directly connected technical resource tie interface between the tower and Moelven’s production facility to meet the requirements of the calculations and tests. In turn, the adaptations in this technical resource tie interface necessitated adaptations in the directly connected technical resource tie interface between Moelven’s production facility and that of the wood supplier, requiring other types of engineered wood to be ordered. Thus, an indirect connection between the technical resource tie interface between the tower and RISE’s laboratory, and the technical resource tie interface between Moelven’s production facility and that of the wood supplier was created. Consequently, four actors were involved in developing the production facility for the tower.

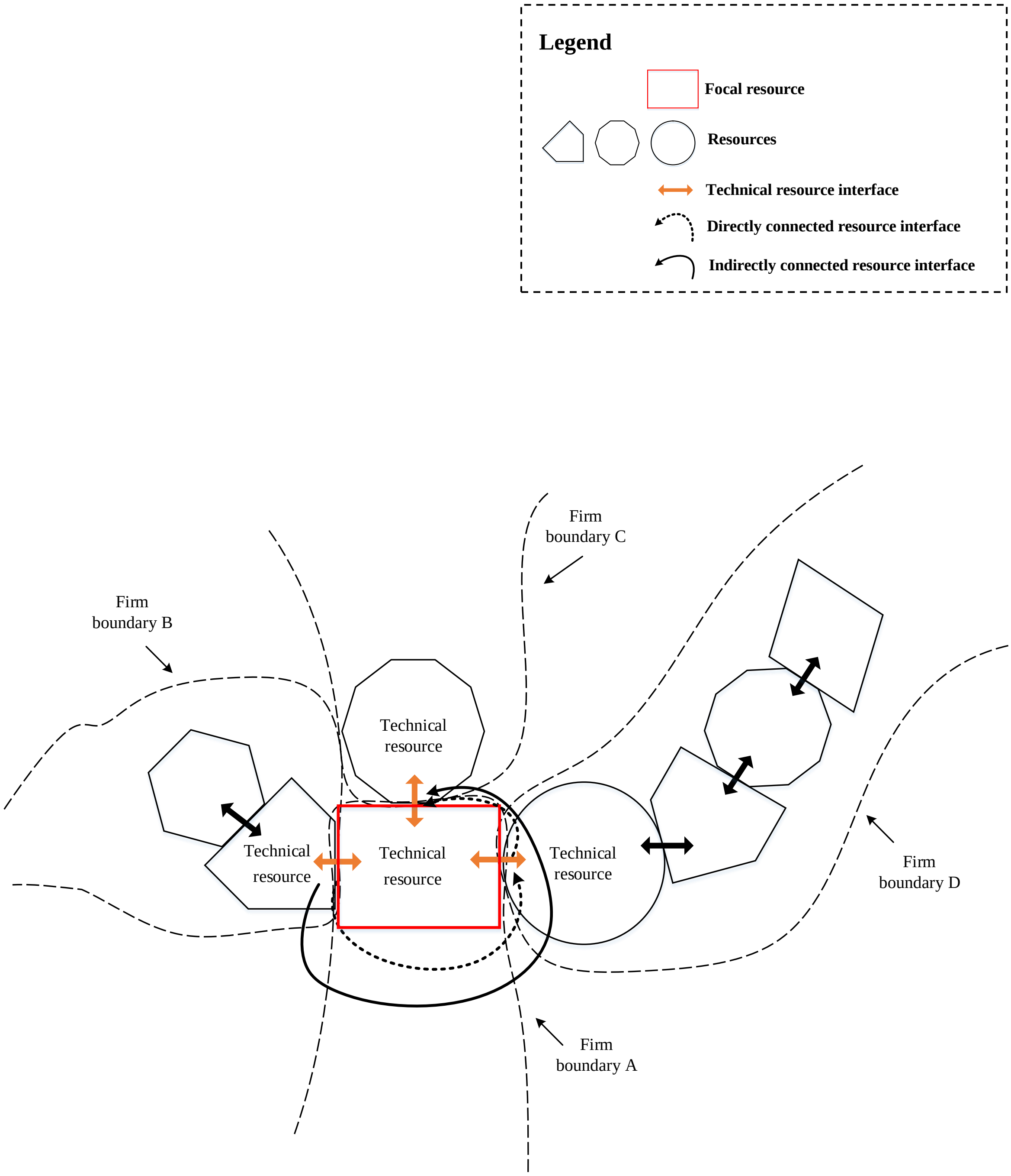


Figure 15. The network effect of a technical resource tie interface

‘A mixed resource tie interface and its effect on an indirectly connected resource collection interface'

The fifth type of resource interaction pattern is shown in Figure 16 and concerns the network effect of a mixed resource tie interface and how it impacts a mixed resource collection interface via two technical resource tie interfaces (vii). One example from the analysis is the process of embedding the wind power tower in the resource constellation related to its development. In the mixed resource tie interface between the wind power industry’s organisational structure and the wind power tower it became clear that the tower should be a certain height to meet industry requirements. Consequently, this impacted the technical resource tie interface between the wood tower and RISE’s laboratory, where these parameters had to be considered by computer programs in the evaluation of the tower’s design. This in turn impacted the technical resource tie interface between the wood tower and the production facility at Moelven, which had to rearrange its production line and create new routines in the connected mixed resource collection interface between the facility and its employees.

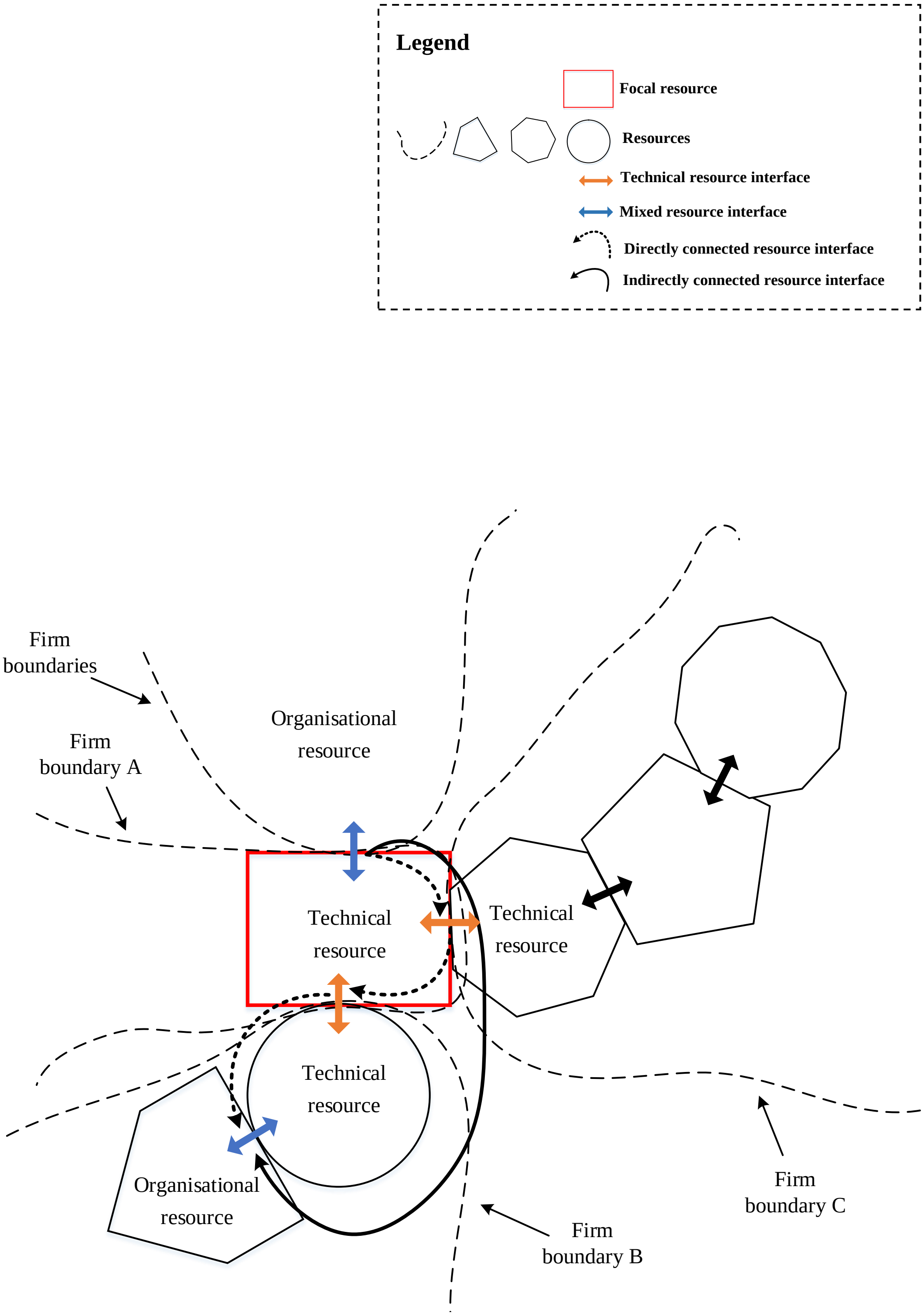


Figure 16. The network effect of a mixed resource tie interface

4.7.3 A comment on the five identified resource interaction patterns

The five resource interaction patterns identified in the previous analysis illustrate different sequences of connected resource interfaces. On the one hand there are the patterns of directly connected resource interfaces:

(1) 'The technical resource tie interface and its effect on a directly connected resource collection interface'
(2) 'The interplay between resource interfaces and its effect on a resource tie interface'

On the other, there are the patterns of indirectly connected resource interfaces:

(3) 'A resource collection interface and its effect on an indirectly connected resource collection interface'
(4) 'A technical resource tie interface and its effect on an indirectly connected resource tie interface'
(5) 'A mixed resource tie interface and its effect on an indirectly connected resource collection interface'

The resource interaction pattern (1) illustrates a basic sequence of connected resource interfaces, specifically the way in which a technical resource tie between two actors can affect the internal resource collections belonging to them. Hence, it shows the importance of adapting internal resources to enable a good fit between two combined resources. As seen in pattern (3), what happens internally in a resource collection may also affect other resource collection interfaces via a resource tie interface. Moreover, resource interaction patterns (2)-(5) have network effects, which means that a third-party actor is affected by what happens in the resource tie between two other actors. In some cases, such as patterns (4) and (5), as many as four actors can be involved. In these cases, the sequences of connected resource interfaces span several firm boundaries. Consequently, all these firms may have to adapt their resource collections, as in pattern (1), to create a good fit between the interfaces within a specific sequence. An important point is the hypothetical notion that all five resource interaction patterns could be visible in the same snapshot of a resource constellation. This could be either as sequences of 'connected' resource interaction patterns in which one pattern triggers the next or as independent patterns visible in the same resource constellation. An early attempt to discuss the effects of the five patterns on a particular resource constellation will be made in Chapter 6.

5. Analysis and implications of versatility

The analysis in Chapter 4 identified five different resource interaction patterns that are central to the process of embedding a resource in a resource constellation. These patterns are strongly related to the resource interfaces and the way in which they are connected to each other, both directly and indirectly, in the resource constellation. Embedding a resource in a resource constellation is a matter of realising the potential versatility of a resource. As Holmen (2001) points out, versatility can be realised either by combining one resource with another to create a new useful resource or by modifying the features of a resource to better fit with existing resources. Each resource has a potential versatility that can be realised through its interaction with other resources. Even though a resource can be combined in an infinite number of ways, its usefulness in these combinations is limited by its features. This chapter aims to analyse how potential versatility can be realised in the resource constellation. On the one hand, it is a matter of exploring versatility by searching and experimenting in the resource constellation, and on the other, exploiting existing knowledge as well as refining existing technologies and processes. As March (1991) emphasises, activities related to exploiting could be perceived as being easier to evaluate as there are more certainties over their resulting consequences. In contrast, exploring activities often have longer time horizons with more diffuse results. Thus, there needs to be a balance between exploring and exploiting to avoid the costs of experimenting without payback. This chapter therefore aims to answer the second research question: How is the versatility of a resource explored in a resource constellation?

In the coming analysis, exploring and exploiting are referred to as two parts of the interaction between two resources in a resource interface. Exploring can be seen as the part of the interaction by which focus is put on figuring out what can be achieved through a relationship and what adaptations need to be made through experimenting and by searching for new possibilities. Exploiting, on the other hand, is more closely connected to business and the need to solve a specific problem. Hence, it could be seen as the part of the interaction characterised by intensive mutual learning, informal adaptations and mutual routines (Ford, 1980). In the part of the interaction that includes exploring versatility, there are a variety of ways to explore modification potential and combination potentials of resources and thus realise potential versatility in a resource constellation. One way to capture this variety is to refer to the intensiveness of explorative events in terms of the number of ways in which a resource can potentially be useful in a constellation. On the one hand, there could be a high degree of exploring in different resource interfaces to enable versatility, such as when embedding the algae in a resource constellation: the algae could potentially be used in at least five different application areas such as skin products, cleaning waste water, solar panels, biofuel and fish food, thus interacting with several resources in the resource constellation. On the other hand, there could be a lower degree of exploring within different resource interfaces to enable versatility, such as when embedding the tower in a resource constellation where the focus is on developing one application area at a time involving a small number of resource interfaces, and therefore primarily exploit rather than explore.

In the interactive process of exploring the potential versatility of a resource, especially with a high degree of exploring, directly connected resource tie interfaces are important for learning how different application areas can be developed. Hence, there is a requirement for adaptations in many technical interfaces, as there are a variety of different resource collections with which the focal (and technical) resource can be combined to make it useful in other actors' processes. It is also evident that the potential versatility of a resource when being developed for many application areas could be realised in the process of its modification. Looking at the algae, it was necessary to remove the nitrogen from the biomass to make it useful in Preem's processes. Moreover, a resource that is subject to a high degree of exploring potential versatility may result in a need to access and make use of other actors' resources, as those internal to the organisation may be too limited to cover all possible application areas. In the example of the algae, it was impossible for SAF to develop and produce skin products, a coating material and a biofuel application in-house. Instead, the start-up made use of the knowledge and equipment of several other actors. When it comes to cases characterised by a low degree of exploring versatility, a smaller number of directly connected resource interfaces were visible. In this case, mixed interfaces together with technical ones play an important part in the process of embedding a resource. One reason for this could be the importance of matching the requirements of a specific industry early on (such as the wind power industry) in order to develop the resource in the right direction.

5.1 Versatility and the resource interaction patterns

In order to realise the potential versatility of a resource, both directly and indirectly connected resource interfaces need to be adapted. Hence, it is important to understand how resource interfaces connect in the resource constellation in order to foresee the impact a new resource will have on it and how existing resources may impact the process of embedding a new resource. One way of doing this is by relating the five resource interaction patterns to the process of embedding resources in resource constellations with different degrees of exploring versatility.

From the first resource interaction pattern, 'the effect of a technical resource tie interface on a directly connected resource collection interface', it is evident that the resource tie interfaces are important and may affect the resource collections of both involved actors. When exploring many different resource interfaces in the resource constellation at the same time to enable versatility of a resource, the resource interaction pattern may replicate and thus occur simultaneously between several actors developing different application areas to realise the potential versatility of the resource. This is a matter of interacting with several resources simultaneously, and consequently a change in a specific resource tie interface between two resources may affect not only the two involved resource collections but also other resource collections across the resource constellation connected to the focal resource. For example, the process of embedding the algae in the resource constellation related to its use for biomass in Preem's production process and removing the nitrogen from it may have had a negative effect on the potential to use the algae's biomass in a future biogas plant. If the technical interfaces within the biogas plant do not suit the new composition of the algae, then neither application can be fulfilled without investing time and money in adapting the algae to each application. In a resource constellation characterised by a low degree of exploring versatility of a resource, the effect of a change in a resource tie interface may be limited to only a few actors. Therefore, the resource interaction pattern is likely to occur less frequently within the resource constellation. Taking the tower as an example, its only function was carrying the nacelle and withstanding external conditions, and hence it was easier to adapt the production facilities at Moelven and its sub-suppliers to produce engineered wood for this purpose. Consequently, the focal resource may be subject to a smaller number of interfaces.

The second resource interaction pattern, 'the interplay between resource interfaces and its effect on a resource tie interface', is visible regardless of the degree of exploring of potential versatility in a resource constellation. Hence, whether the potential versatility of a resource is explored in several different interfaces or only a few, it is important to embed the resource in the organisational resources of, for instance, the user firm. A high degree of exploring potential versatility could result in a high number of organisational resources to adapt to in order to realise the potential versatility of the resource. In addition to this, if a resource is perceived as being highly innovative, the process of embedding it in existing organisational structures and activated resource structures will force the interplay to take place between resource collections that mutually adapt to each other. The process of embedding the algae in Preem's production processes provides a clear example of how a lack of mutual adaptation between visions and working routines can result in a move towards other actors, such as Smögen Lax. The company and SAF not only shared a vision of creating a sustainable future but also had rather flexible resource structures that could adapt to the prerequisites of the algae. This was also the case with the cosmetics company, which not only shared the vision of incorporating UV protection into skin products but also had an organisational structure in which the algae could easily be embedded. Having a resource that is subject to a low degree of exploring potential versatility, i.e. aimed at just a single or small number of applications, often only requires limited interplay in the using setting, however that interplay may result in the need to force the resource to fit into the activated resource structure and in some cases lower the degree of innovation. This was the case with the turbine where the initial application areas, extracting energy from natural water streams and creating an on-grid solution related to water pipes, changed to developing an off-grid solution to provide a smaller amount of electricity for measurement devices. Hence, product development was guided by user demand and thus the resource collection linked to the user.

The third resource interaction pattern, 'a resource collection interface and its effect on an indirectly connected resource collection interface", was visible in the study in cases characterised by both high and low degrees of exploring potential versatility. When trying to embed a resource subject to a high degree of exploring potential versatility in a resource constellation, it is likely that it will be exposed to a variety of different kinds of resource collections. As mentioned above, it is preferable that these resources are characterised by flexibility and that there is a willingness to adapt both the organisational resources and the activated resource structure to make the new resources useful in the resource structure. However, a flexible resource collection may already include some fixed substructures which are perceived as fundamental to a counterpart's processes. A resource that is subject to a high degree of exploring potential versatility can benefit from being introduced to a resource collection that has well-functioning technical interfaces that work well with the new resource. Flexibility may then be exhibited by the adaptation of the resource tie interface between the two resource collections to facilitate access to fixed substructures. One example could be the resource collection of the cosmetics company, in which one of the core processes is constituted by the technical and organisational resources that contribute to building up the R&D department. Hence, access to this substructure was enabled via the organisational resource tie interface between the organisational structures of SAF and the cosmetics company by letting staff from the marketing, purchasing and R&D departments meet SAF's CEO. This in turn may have affected the internal organisational resources at SAF in terms of the direction of internal product development activities. Moreover, when it comes to resources subject to a low degree of exploring potential versatility, a resource collection interface within the resource collection of the focal resource may indirectly impact that of another firm. As the study shows, this is more common when talking about a producing rather than a using setting, as the user has often already set the stage for the application of the focal resource. One example is the tower. In this case it was evident that the wind power industry and its related actors were moving towards building larger towers and rotors. Hence, within the resource collection interface between the master's thesis students and the tower, the design parameters were calculated with regard to user demand, which affected how the resource collection at Moelven developed, for example in the adaptation of the resource collection interface between the employees and the production facility.

The fourth interaction pattern, ‘a technical resource tie interface and its effect on an indirectly connected resource tie interface’, involves resources that are subject to both high and low degrees of exploring potential versatility but with different implications for each. When considering a resource that is subject to a low degree of exploring versatility a change in a technical resource tie interface may change an indirectly connected technical resource tie interface belonging to a third actor. Considering that a resource subject to a low degree of exploring potential versatility has a focused application area and may need to be embedded in an established industry, there will be a more stable and defined resource constellation for it to be adapted to. Hence, while this resource interaction pattern may be seen infrequently and involve the same actors, for resources subject to a low degree of exploring versatility, the process of embedding a resource subject to a high degree of exploring potential versatility may include several occurrences of this pattern and a greater number of actors. Consequently, when it comes to resources subject to a high degree of exploring potential versatility, all the technical adaptations between the focal resource and surrounding resource collections affect not only one indirectly connected technical resource tie but several in parallel. This may have consequences for how well adaptations can be carried out. For example, removing the nitrogen from the algae biomass to fit Preem’s production process could have influenced its usefulness in other technical resource ties, such as its potential application related to biogas.

The fifth resource interaction pattern, ‘a mixed resource tie interface and its effect on an indirectly connected resource collection interface’, was evident when dealing with resources subject to low degrees of exploring potential versatility. One reason for this could be the need to adapt the focal resource to one specific purpose, for example the process of embedding the wood tower in the working routines of the wind power industry. Relying on only one potential application area means starting by fostering acceptance of the product by understanding what specific customers want. Understanding trends and visions related to the application, such as for taller towers and large rotors in the wind power industry, forces technical resource ties to adapt both directly and indirectly and later affects mixed resource collection interfaces belonging to third-party actors. Assuming a resource subject to a high degree of exploring potential versatility, this pattern may repeat in the resource constellation just as in the case of the fourth pattern. This will have implications for the way different ties are synced and the choice over how time and resources are allocated to adapt resource ties.

5.2 Bounded infinite versatility as exploring and exploiting resource interfaces

The previous analysis showed that the resource interfaces play a significant role when it comes to exploring potential versatility of a resource in interaction. Hence, it is in the resource interfaces certain features of the resources both enable and restrict versatility. Coming back to Holmen (2001)'s concept of 'bounded infinite versatility', there is an unlimited number of ways in which resources can be combined, however due to their features there are only a limited number of ways that they can be made useful. Looking specifically at the algae, turbine and tower, it is interesting to study the trade-off in versatility across different resource interfaces, as adaptations of features in certain interfaces may restrict or enable versatility in others. Moreover, it is interesting to study the interplay between exploring and exploiting interfaces with regard to the specific resources and their three business network settings.

Taking the technical resource tie interface as a starting point, it can be seen to both realise and restrict versatility of a resource. When a technical resource tie interface is exploited in terms of its adaptation to solve a specific problem, it can act as a crucial enabler for realising potential versatility as it opens the possibility of exploring several other technical resource tie interfaces. For example, in the case of the technical resource tie interface between the algae and the fish water, the nutritional qualities of the water facilitated the exploring of several other important resource interfaces. Firstly, it facilitated the directly connected technical resource collection interface between the harvesting technique and the algae. Additionally, it stimulated the directly connected resource tie interface between the algae and UGOT's laboratory. Even though the resource interface between the algae and UGOT's laboratory had reached the exploitation phase with regard to solving certain specific problems, it opened up the possibility of exploring new solutions to other types of problems. Hence, the exploration of the UV-blocking characteristic became an exploitative process as it helped create the technical resource tie interface between the algae and the cosmetics company's laboratory. Furthermore, exploiting organisational resource tie interfaces may help realise the potential versatility of resources by shaping important technical resource tie interfaces, for example the organisational resource tie interface between the organisational structures of SAF and Smögen Lax, the vision and ideas of which helped create the technical resource tie interface between the algae and the fish water.

There are also resource interfaces that may restrict versatility of a resource. By exploiting some resource interfaces, others may not progress beyond the exploring stage of searching and experimenting. One example could potentially be the technical resource tie interface between the algae and Preem's production facility, through which it became evident that the amount of nitrogen in the bio-crude oil from the algae had to be reduced. Had the collaboration continued and reached the exploiting stage, reducing the nitrogen content may have resulted in bounded versatility in terms of the algae's potential use in other resource ties, such as the biogas plant or as fish fertiliser. Another example is the turbine and its potential use in other applications than cities' water pipes. In the context of the technical resource interface between the generator and the turbine, the generator was developed to extract an exact amount of energy from the water flow in the pipes. This required the development of specific features in the generator, such as the coils. However, by exploiting the resource interface between the turbine and the generator to solve the problem presented by the technical resource tie interface between the turbine and the water, it may be that future opportunities to explore and later exploit new interfaces are restricted. For example, it may be difficult to develop the applications of district cooling and irrigation if they require a different flow of water and further development of the generator as a result. It may mean that it is too costly and/or difficult to proceed with them. Consequently, these new resource interfaces may become bound by the process of exploiting in a connected resource interface.

Each of the above-mentioned examples are characterised by a 'one-way' situation where a resource interface either enables or restricts another connected resource interface to develop. There are also examples of a 'two-way' situation in which two connected resource interfaces can enable or restrict a resource interface to develop. In this way, the potential versatility of a resource can be realised, restricted or take a different form to what was originally expected. One example of this is the technical resource tie interface between the turbine and the generator, which had to be developed with regard to the measurement device and the need to provide enough electricity to produce the required amount of data. However, its versatility was restricted by the technical resource tie interface between the turbine and the water, specifically the requirement to maintain a certain level of water pressure, which constrained the amount of energy that could be extracted from the water flow. Relying on just a single resource interface to realise the potential versatility of the turbine in combination with the measurement device would have been insufficient, as this could not have been achieved without creating a working interface between the turbine and the water. Another example is the creation of a technical resource tie interface between the wood tower and Moelven's production facility. Initially, certain restrictions on the dimensions of the tower were set by the technical resource tie interface between it and the RISE laboratory. Therefore, in order to realise the potential versatility of the tower in the production setting, it was essential to adapt the features of Moelven's production facility, such as by adding an additional production line. However, adaptations in the mixed resource collection interface between the employers and the production facility were also required. New tasks had to be assigned to both parties to facilitate their integration into the new production line. Therefore, in this example, it can be seen that realising the potential versatility of the tower, in the context of

Moelven's production facility, was only possible through the adaptation of two directly connected resource interfaces.

The process of realising versatility of a resource requires continuous exploring of new resource interfaces and exploiting of existing ones. When embedding a resource in a resource constellation there is emphasis on exploring interfaces in developing, producing and using settings (Håkansson & Waluszewski, 2007). However, there needs to be a balance between exploring new and exploiting existing knowledge in these interfaces, and within this dynamic certain patterns emerge. These are very much dependent on the uniqueness of the specific features of the resource in question. With regard to a resource with many potential application areas, and thus subject to a high degree of exploring potential versatility, several resource interfaces may be explored in the search for potential application areas. In the case of the algae, these included cosmetics, fish food, solar panels, fuel, batteries and biogas. Resource interfaces in many different using settings were explored together with a variety of actors, and it was here that many of the bounded interfaces, resulting from the algae's unique characteristics, became visible. Many of the resource interfaces that were exploited through these interactions were found in producing or developing settings, in which execution and implementation are more easily visible. The implementation of production processes at Smögen Lax, and R&D activities at UGOT's laboratory helped to initiate the search for new interfaces in the using setting and exploit previously explored interfaces. The use of the algae in Preem's refineries was facilitated through the adaptation of UGOT's laboratory to add an additional step in the production process to lower the product's nitrogen content. Furthermore, the technical resource tie interface between the algae and the fish water at Smögen Lax facilitated the cultivation of larger amounts of silica to test, enabling the previously bound resource interface between the algae and the clients' facilities.

The turbine was subject to a lesser degree of exploring versatility than the algae, and it was mainly carried out in conjunction with only a single actor. By exploring the mixed interface between the turbine and K&V's organisational structure to develop the idea of extracting energy from water pipes, it was possible to modify the turbine and generator to fit their new context. This resulted in the exploration of new resource interfaces in the developing and producing settings. Developing the generator with regard to the setting of the measurement device and finding suitable suppliers in a producing setting was initially an interactive and iterative process of experimentation. As the resources were adapted to each other, the focus of development shifted to refining the turbine technology in all three business network settings to fit the specification of the pipes and exploit the existing interfaces between the water pipe, consultants, measurement device and supplier in Kalmar's production facility.

A similar pattern can be seen when it comes to resources that are subject to a lower degree of exploring new interfaces, such as the wind power tower. However, the exploring of new interfaces in interaction in the using setting quickly resulted in a specific application area producing a large stackable wind power tower from wood. Making use of and refining existing technology at RISE, and the master's thesis students' knowledge, was important when it came to exploiting existing resource interfaces in the developing and producing settings. Moreover, refining the existing processes at Moelven helped to create the right prerequisites for the tower's production. Hence it can be seen that resources that are subject to a lower degree of exploring new interfaces may facilitate the exploiting of existing resource interfaces at an early stage in their development. A potential reason for this could be that a focused application area reduces the need for organisations to explore new interfaces and concentrates their focus on making existing ones to work.

With this in mind, the definition of 'bounded infinite versatility' could be explained as the relationship between restriction and enabling of versatility in the resource interfaces, that is, the limitation in usefulness is not only decided in the particular resource interface but dependent on directly and indirectly connected resource interfaces. For this reason, it is important to consider several resource interfaces at the same time and explore and exploit them simultaneously to realise the potential versatility of a resource. However, it is clear that the sequence of actions in a specific resource interface is not always characterised by a pattern of exploration followed by the perpetual exploitation of a resource interface. The analysis of UGOT's laboratory as a resource shows this to be the case; from this example it is clear that it helped explore new features of the interface with the algae, whilst at the same time exploiting and executing ongoing R&D activities.

Exploring versatility of a resource in a resource constellation is a matter of exploring and exploiting resource interfaces in the three business network settings. Hence, in order to realise the potential versatility of a resource it is important to understand the trade-off between adapting one resource interface to enable an application and, at the same time, restricting other resource interfaces and future application areas. It may be that a focused application area is preferable early on, and in some cases this results in going from the exploration to the exploitation stages of a resource interface relatively fast. However, in many cases there is an ongoing search for how to facilitate the useful application area of the resource by exploring many resource interfaces at the same time. It may be necessary to restrict versatility in certain resource interfaces in order to enable versatility in others. Consequently, there is no clear answer to the question of whether a high or a low degree of exploring versatility is more desirable than the other since it depends on which resource constellation the resource is being embedded in. However, exploring new resource interfaces in interaction takes time, energy and resources and these are not always available to start-ups. If it is possible to predict the impact of exploring activities in specific resource interfaces on other connected ones, it may be easier to evaluate if these exploring activities are worth trying.

6. The complexity of becoming part of the Swedish energy system: exploring versatility in three energy-related resource constellations

This chapter uses the knowledge produced in the previous chapters on the empirical setting of the Swedish energy system. Firstly, the Swedish energy system is analysed as a resource structure by identifying different resources important for the system. Secondly, the five resource interaction patterns are analysed in relation to three specific energy-related resource constellations; solar power, micro hydropower and wind power.

6.1 The Swedish energy system as a resource structure

Today's energy system is a result of the prerequisites and requirements of a relatively small number of actors. It can be seen as a business network of actors connected through different activities and resources (Håkansson & Snehota, 1995) in which business relationships have been essential to developing the system. The development from small- to large-scale electricity production during the first half of the 20^{th} century has its basis in several central business relationships. One example is the business relationship between the buyer Vattenfall and the seller ASEA. This relationship enabled technological collaboration that ensured the distribution of electricity from large hydropower stations in the north of Sweden to cities in the south. The first technical collaboration between the two actors, initiated in 1904, concerned the adaptations of what Håkansson and Waluszewski (2002a) refer to as technical resources connected to the Trollhätte power station. Since the new power station run by Vattenfall facilitated higher voltage and power output than previous power stations, ASEA had to develop new breakers that could handle this increase. Testing the breakers with the generator at the power station revealed that the technical resources were not compatible with each other. Several explosions occurred at the power station before the two parties could agree that it was preferable to have a thinner break contact as well as more space for air in the oil box connected to the breaker (Fridlund, 1999).

The technological development of the Swedish energy system is a result of resource combinations both within firms and across firm boundaries. This is in line with Håkansson (1987)'s assumption that technological development is a result of a 'network' of different actors. There are several existing key resources in the Swedish energy system that have been developed over a long time and through collaboration between actors for specific purposes, such as the production of oil products and electricity as well as the distribution of electricity and gas. The Swedish energy system can be considered a resource structure with a high degree of technological and organisational adaptation between the firms in the system. One example is the grid system, which is a central technical resource structure built out of several resources in the energy system over a long time, for example the 380-kV power line between Harsprånget hydropower station in the north and Hallsberg in the south that was built in 1952 and is still in use today. Over the years the grid system in Sweden has been subject to change as a result of the adaptation of the facilities connected to it such as the hydropower stations and nuclear power plants with stable production of electricity. In turn, these facilities have internal resources that have been developed over many years for this reason and through large investments by companies. Thus, the resources related to both the production and the distribution of electricity have strong connections to each other.

However, today the grid system faces the challenge of adapting to a more unstable supply of electricity generated by solar energy and wind power. Many sets of connected relationships (Anderson et al., 1994) are affected by changes in the interaction between the grid system and renewable energy sources such as solar and wind power, and at every point there must be a balance between the production and use of electricity. Adapting the grid system to new renewable energy sources requires that the resources at large facilities, such as hydropower plants, adapt to accommodate an unstable supply of electricity to maintain a stable overall supply for users. In conjunction, parts suppliers to hydropower plants need to adapt their facilities to produce the technology needed to adapt hydropower plants to a more unstable supply of electricity. Furthermore, the resources of Sweden's three nuclear power stations, including the eight reactors, will be subject to change when renewable energy sources are connected to the grid system. Nuclear power stations may act as frequency controllers to maintain the balance between the production and use of electricity. Consequently, this new dynamic will require currently combined resources at the plants to be disconnected to facilitate the development of new ways to minimise deterioration of the facilities.

Another example of a resource structure is the one connected to oil refineries, which has been adapted over many years for the purpose of producing oil products. Today, 24% of the energy used in Sweden comes from oil. The reasons for the difficulties in disconnecting existing resource combinations are, on the one hand, the large income generated by selling oil products, as there is still a large market for them, and on the other the expense of changing existing facilities. Adapting refineries to produce renewable products will cost oil companies billions. These large facilities are similar to the ones mentioned by Håkansson and Waluszewski (2002b), which consist of many interfaces with high economic values. A refinery consists of several operations, each of which has a substructure of resources that need to function in relation to each other. Adding a new step to the process, such as a new isomerisation facility to improve the quality of the liquid rosin produced, also requires adaptations to connected resources such as the oil tank refinery field needing to increase its storage volume.

Bringing new renewable energy technology into the Swedish energy system to enable the transformation towards a 100% renewable energy system will require new resource combinations both in and across firm boundaries. As stated by Gadde et al. (2010), adding a new resource to an existing resource collection is challenging since the existing resource structure has often been developed over many years and in connection to many other resources. Moreover, accommodating a new resource means adapting not only interacting resources but also those indirectly connected to them.

One way to understand how a new resource can become useful in the resource structure of the Swedish energy system is to consider the different interaction patterns that occur when embedding focal (and technical) resources in the resource constellations that make up the resource structure of the Swedish energy system. Thus, this chapter aims to answer the third research question: What are the effects of the resource interaction patterns on a resource constellation? By way of example, the following analysis will illustrate the process of embedding a new technical resource in the resource constellations of solar power, wind power and micro hydropower.

6.2 Embedding a resource in the resource constellation of solar power

Solar power is expected to play an important role, together with wind and water, in transforming the Swedish energy system to 100% renewables. Solar panels transform the energy from sunlight into electricity that is later used by, for example, households, industry and the transport sector. Today, the electricity produced by solar panels is distributed through the grid system as well as produced locally for use by households. Moreover, the technology is used in various pilot tests, such as E.ON’s local energy system in Simris. In 2018, the Swedish energy trade organisation estimated that 254 of 38,851 Megawatts of power availability was generated from solar power and owned by individuals or small and medium-sized companies. However, the organisation estimates that within 5-10 years a significant number of its members will invest in solar power and thus the production of electricity from solar power will increase. As the expansion of solar power continues, the need for better technology grows. The current technology in the energy system also needs to be adapted to make solar panels useful.

The solar power industry can be viewed as what Håkansson and Snehota (1995) refer to as a substructure of the energy system in which several relationships are ‘tied in’ to one another and dock with other substructures of the energy system. A new technical resource may be brought into the resource constellation of the solar power industry by integrating it with a component that will later be integrated into solar panels. Hence, depending on the type of resource and degree of adaptability of the resource collections that make up the substructure, different resource interaction patterns may affect the resource constellation differently. Figure 17 shows a simplified illustration of the resource constellation of solar power and the different resource interaction patterns that may occur when trying to embed a new technical resource in it. This figure will form the basis for the analysis that follows.

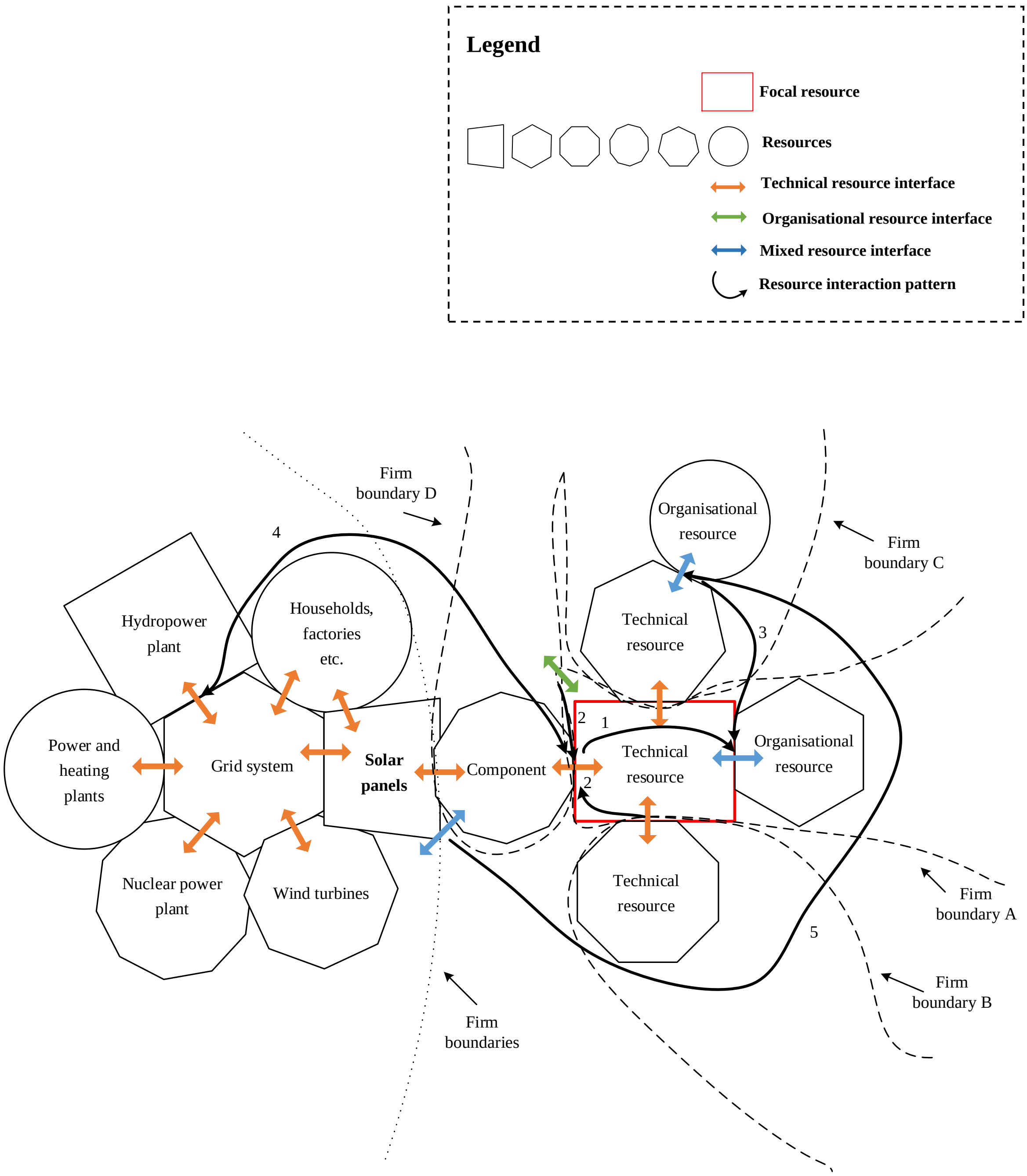


Figure 17. Embedding a technical resource into the resource constellation of solar power

In order to make use of a new technical resource in the context of solar power, it is important to understand the effect of a technical resource tie interface on a directly connected resource collection interface. This pattern is shown as number (1) in the above figure and can occur in the creation of a technical resource tie interface between a focal resource and the component with which it needs to be combined to create a new useful resource in the resource constellation of the solar power industry. For example, in the case of the algae, this was achieved by using the silica as an ingredient in the coating material and then integrating it directly into the solar panels. Hence, features of the technical resource tie interface are revealed and may require modification before the two resources can be combined as a new useful resource to make solar panels more efficient. Thus, the technical resource tie interface between the technical resource and the component will affect how directly connected resource collection interfaces within the firm must be adapted to develop new features. In the case of a focal resource subject to a high degree of exploring versatility a change in the focal resource collection may restrict or facilitate the possibility of developing other applications.

Furthermore, in order to enable a technical resource tie interface between a technical resource and another component that together can form a new useful resource, it is important to consider the role of other directly connected resource tie interfaces. Hence, the interplay between technical and organisational resource interfaces (2) is necessary in many cases to facilitate the creation of a new resource tie interface. For example, it is important that the two actors' organisational resources that are being combined are aligned. Sharing the same vision and having organisational structures that match help facilitate the creation of a technical tie interface. Furthermore, there may be other technical resource tie interfaces that hinder or facilitate the formation of a new technical resource tie interface, for example those related to R&D activities with universities and research institutes, or other collaboration partners. Taking the algae as an example, a technical interface between the cosmetics company's laboratory and the algae would not have been possible without there being a good match between the organisational structures of the two companies. In this case, there was a unit at the cosmetics company assigned to deal with new technology provided by start-ups. Moreover, the functioning technical resource tie interface between the algae and the fish water at Smögen Lax facilitated the cultivation and harvest of the algae in sufficient quantities to be tested at the cosmetics company.

When a new technical resource becomes embedded in the resource constellation of solar power, consideration must be given to how the resource constellation related to the development and production of the resource will impact its use in the resource constellation of solar power. One example of how a mixed resource collection interface can affect other resource interfaces (3) is in the interaction between a production facility and its organisational structure. Depending on whether the parts producer can rearrange its organisational structure, e.g. by reassigning staff or setting up a new unit to help adapt production to suit the required features of the technical resource in the technical resource tie interface between the technical resource and the component, the indirectly connected resource collection interface between the focal resource and its organisational structure may be forced to adapt. With regard to the algae, if the mixed resource collection interface between the UGOT's laboratory and its staff would not have entailed the knowledge and equipment needed to reveal the UV characteristics and thus directed the use of the silica in another direction, it would probably impact the development of the mixed resource collection interface between SAF's organisational structure (vision) and the algae.

As well as resource collections that are directly tied to the technical resource, there are resource interfaces that are indirectly connected to the technical resource and may affect how well a technical resource can be embedded in the resource constellation of solar power. The network effects of technical resource ties (4) that are directly or indirectly connected to solar panels may serve to hinder or facilitate indirectly connected resource tie interfaces between a technical resource and a component. An example is solar panels, which do not work in isolation but create interfaces to other resources such as the grid system and households. Additionally, the grid system is connected and adapted to several other resources of nuclear power and hydropower plants. These resource interfaces have been developed over many years and thus the resource structure of the grid system, which docks into the resources of nuclear power and hydropower plants, makes it hard to introduce new resources to the outskirts of the structure. Hypothetically, the technical resource tie interface between the hydropower plant and the grid system constitutes adapted features such as stable demand for electricity to the grid system. This resource interface will be a characteristic of the new 100% renewable energy system in Sweden, of which hydropower is seen as the linchpin. Hence, a technical resource tie interface between a technical resource and a component may affect how an indirectly connected resource tie interface is developed. By developing an interface to include features that can dramatically improve the uptake of solar power, the technical resource tie interface between the solar panel and the grid system will change in terms of providing a larger (although still unstable) supply of electricity. The indirectly connected resource tie interface between the grid system and the hydropower plant will result in the development of a technology that suits this new supply of electricity to the grid system. Conversely, a technical resource tie interface between hydropower plants and the grid system may restrict the development of a technical resource tie interface between the focal resource and the component. A possible scenario could be that changing a hydropower plant's resource collections may be perceived as being too costly, thus rendering the use of solar power on a larger scale impossible. Consequently, a technical resource tie interface between the focal resource and the component would be dissolved.

Having a focal resource that is subject to a low degree of exploring versatility would probably result in a situation in which a totally new resource had to be developed in order to find a new application area, whereas a resource that is subject to a high degree of exploring versatility may lead to a wider focus on parallel application areas.

Mixed resource tie interfaces are also important for enabling a technical resource to become part of the resource constellation of solar power. The network effect of a mixed resource tie interface (5) impacts the usefulness of a resource in its target context. In the case of the solar panels, the component was made useful through the interface between it and the organisational resources of the solar panel company, specifically how well the new technical resource fit the solar panel producers' organisational structure and visions. If adaptations need to be made, these will affect the directly connected technical resource tie interface between the component and the focal resource, which will also need to be adapted and may, in turn, affect the indirectly connected mixed resource collection interface between, for example, the producer's production facility and its staff. Consequently, new working routines need to be implemented or new staff employed.

6.3 Embedding a resource in the resource constellation of micro hydropower

Water has been used as an energy source for hundreds of years, and today hydropower is considered the linchpin of the Swedish energy system when transforming it to a 100 % renewable system. According to the Swedish Energy Agency, it accounts for 11% of all energy sources used and 42% of the total power availability in Sweden. The Swedish energy trade organisation estimates its power availability to be 16,301 of a total of 38,851 Megawatts. Water is also an important renewable energy source that can be used on a micro level to produce electricity to be supplied locally. One example is the use of water flow in cities' pipes to generate electricity. The modern water pipe system can be considered a resource structure which first started to be introduced in large cities in Sweden in the middle of the 19th century[62]. The water pipe system is a resource that transports water through cities and physically connects several other resources, such as water cleaning facilities, water towers, households and waste water treatment facilities. The system is planned to last at least a hundred years, and changing it to integrate new resources is not an easy task since it has to be done without disturbing the water supply.

[62]Andersson, A-L, 'Svenska vattenledningar och vattenreservoarer 1860-1910', 1971, http://www.eber.se/litt/bil/svenska-vattenledningar-och-vattenreservoarer.pdf,

Figure 18 shows a simplified illustration of the resource constellation of micro hydropower and the process by which a new technical resource can be embedded in it. In this case, a focal resource may need to be combined with a component to create a new technical resource that accommodates the function of the water pipes. The focal resource does not specifically have to be a feature of the component, but the component is a feature of the focal resource. Hence, there need to be two functional technical resource tie interfaces between the focal resource and the water pipes as well as the component and the water pipes to make it work. Firstly, consideration needs to be given to the effect of the technical resource tie interface (1) between the focal resource and the water, since features of the water, including the flow, may impact how the resource collection interfaces develop. For example, parts of the focal resource need to be adapted to avoid pressure drops. A resource that is subject to a low degree of exploring versatility and thus only has this purpose, could potentially benefit from having a specific resource collection to adapt to and then be replicable in other similar resource collections. However, it is still necessary to understand the specific features of the water, as pressure may differ depending on which water pipe system is being used. For example, the micro turbine was developed with regard to a specific resource collection from an early stage to test its ability to extract energy and produce electricity to measure leakages in the water pipe system. This concept was later transferred to other cities where modifications had to be made to the turbine.

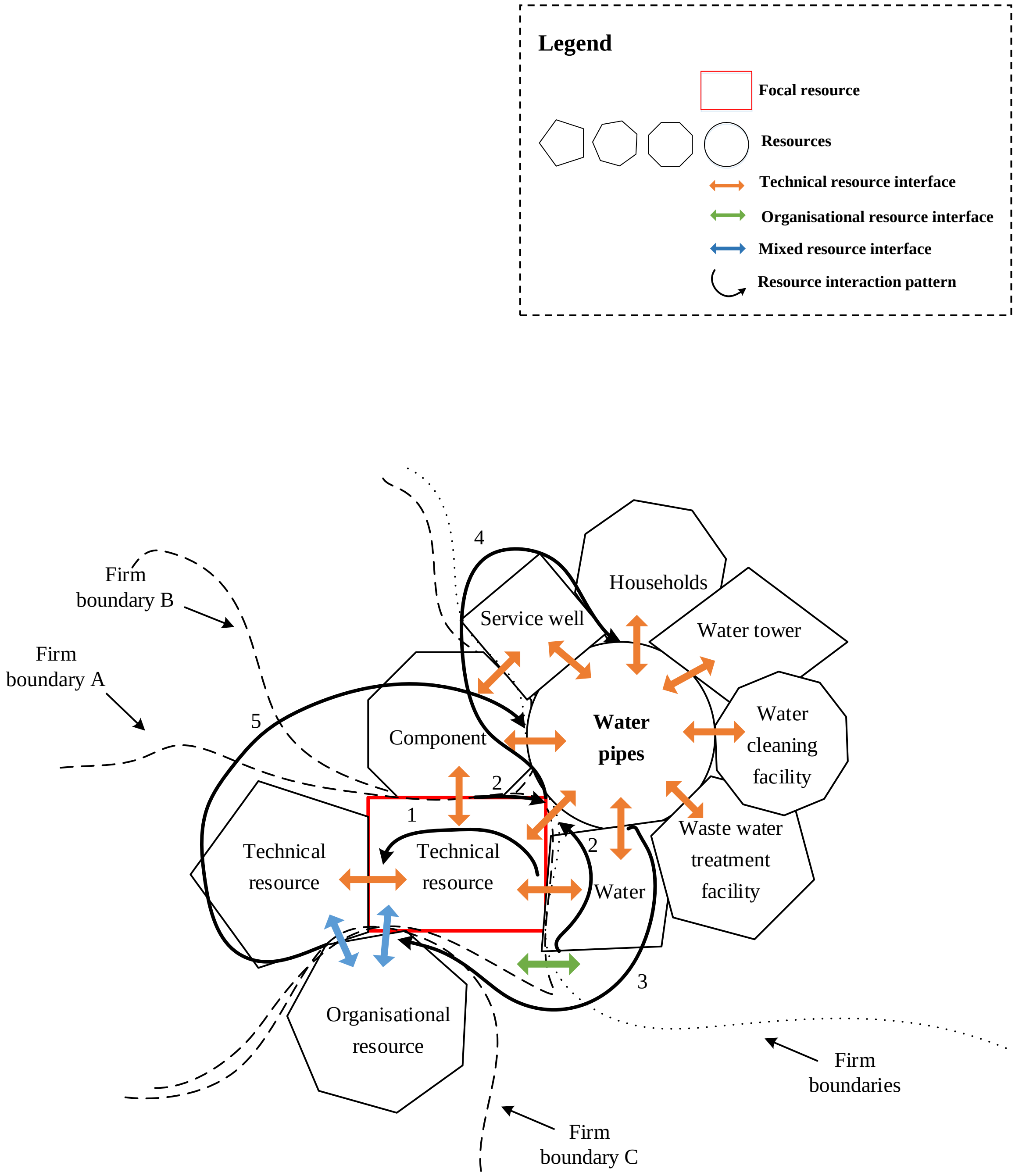


Figure 18. Embedding a technical resource into the resource constellation of micro hydropower

Moreover, several interfaces are required to work in parallel to facilitate the creation of a technical resource tie interface between the focal resource and the water pipes (2). It is important to understand the resource structure of the water pipes and to be open to making the necessary adaptations to become part of the resource constellation. As the pipes are permanent and have a specific purpose that cannot be changed, the focal resource needs to accommodate the working routines of the water pipe industry. Hence, adapting this organisational resource tie interface between the organisational structure of the industry and the organisational structure of the firm, by lowering the innovation threshold to meet the actual needs of the industry, is one way to go. Together with a functioning technical resource tie interface between the focal resource and the required component, this will facilitate a new technical resource tie between the focal resource and the water pipes. For example, it would not be possible to integrate the turbine into the pipes if it did not adapt to the existing industry standards for measuring leakages. Moreover, the measurement device had to be a feature of the turbine in order to provide a complete solution for the sewage companies. Having a resource that is subject to a lower degree of exploring versatility also made it easier to focus on the development of the specific application area to meet the requirements of the industry.

Another important resource interaction pattern to consider is that of the network effect of a resource collection interface within the water pipe system (3). As the water system already has specific requirements that cannot be changed, such as minimum pressure and the need to avoid contamination due to its connection to, for example households, there may be an effect on how the technical interface between the water and the focal resource develops. Other connected resource interfaces, inside the resource collection of the focal resource's firm and those belonging to other actors, will have to be adapted to enable the development of a resource tie interface between the water and the focal resource. One example is the indirectly connected resource tie interface between the technical resource, with the potential to become part of the resource constellation of micro hydropower, and the organisational resources belonging to other firms. These resources could include consultants that are hired to develop the focal resource and are restricted by the existing features of the resource tie interface between the water and focal resource. If the focal resource is subject to a low degree of exploring versatility, it may be that the mixed resource interface between the consultants and the focal resource is developed with certain features that make it applicable to all types of pipes, assuming they conform to a standard size and flow of water. However, a focal resource subject to a higher degree of exploring versatility demands that consultants have broad knowledge, or different types of consultants will need to be hired.

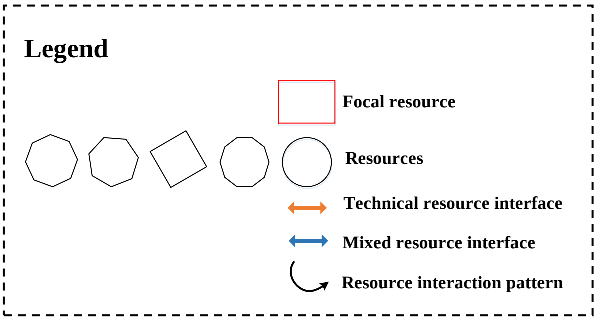
The network effect of a technical resource tie interface (4) and the impact of the interface between the focal resource and the water pipes on an indirectly connected resource tie could result in several different scenarios. One example could be that the focal resource stops the water from flowing in the pipes for a variety of reasons, such as the technical resource tie between the focal resource and the water pipes not being well adapted to each other. This, in turn, may impact the indirect resource tie interface between the water pipes and households by disrupting the water supply to households. For example, it may be that the mechanical parts of the turbine do not fit within the size of the water pipes, impeding the water flow. As the water pipe system has been developed in a standardised way and shaped according to other resources, it is difficult to change the pipes to fit the turbine. In the case of disruption to the water supply, it is important that there exists a technical resource tie interface between, for example, a service well and the water pipes to enable the focal resource to be fixed easily. This interface, in turn, needs to be adapted so that the pipes and the focal resource are easy to reach and enable a temporary arrangement by which the water can pass the blockage in the pipe. By doing this, it is possible to avoid a disruption to the flow that will eventually impact the technical resource tie interface between the households and the water pipes.

It is also important to consider how a mixed resource tie interface may impact other indirectly connected resource tie interfaces (5). For example, the changes made in the mixed resource tie interface between the focal resource and, for example, the consultants to be able to adapt the focal resource to work well with the water pipes may impact other resource tie interfaces such as the one between the component and the water pipes. One example could be that the features of the mixed resource tie interface between the consultants and the generator are developed so the turbine does not extract too much energy from the water. Consequently, this impacts how much electricity the component or, in other words, the measurement device can produce in the technical resource tie interface between the measurement device and the water pipes.

6.4 Embedding a resource in the resource constellation of wind power

Today, wind power constitutes approximately 17% of the electricity produced according to the Swedish energy trade organisation, specifically, 6691 Megawatts of power was available, primarily produced on an individual level as well as by small and medium-sized companies. In contrast to solar power, large energy companies own and produce enough electricity from wind power to be statistically relevant. Hence, unlike solar power, wind power is already used in a significant volume in the Swedish energy system, with plans to expand it in the coming years. Currently, Svenska Kraftnät is developing the national grid system to be able to connect it to more wind power farms in the future. The trend within the wind power industry is to build higher tower and use larger rotors to increase the power generation potential by reaching higher and stronger winds. This will also decrease the negative impact on the environment and land use, as it requires fewer installations.

Embedding a technical resource in the resource constellation of wind power may take the form of combining a focal resource directly with the technical resource of the wind turbine. One example is the wood tower, which has the potential to become part of the wind power solution without first being integrated into another component. Figure 19 shows a simplified illustration of how this may look and will act as a starting point when analysing the effects of the different resource interaction patterns on the process of embedding the resource.



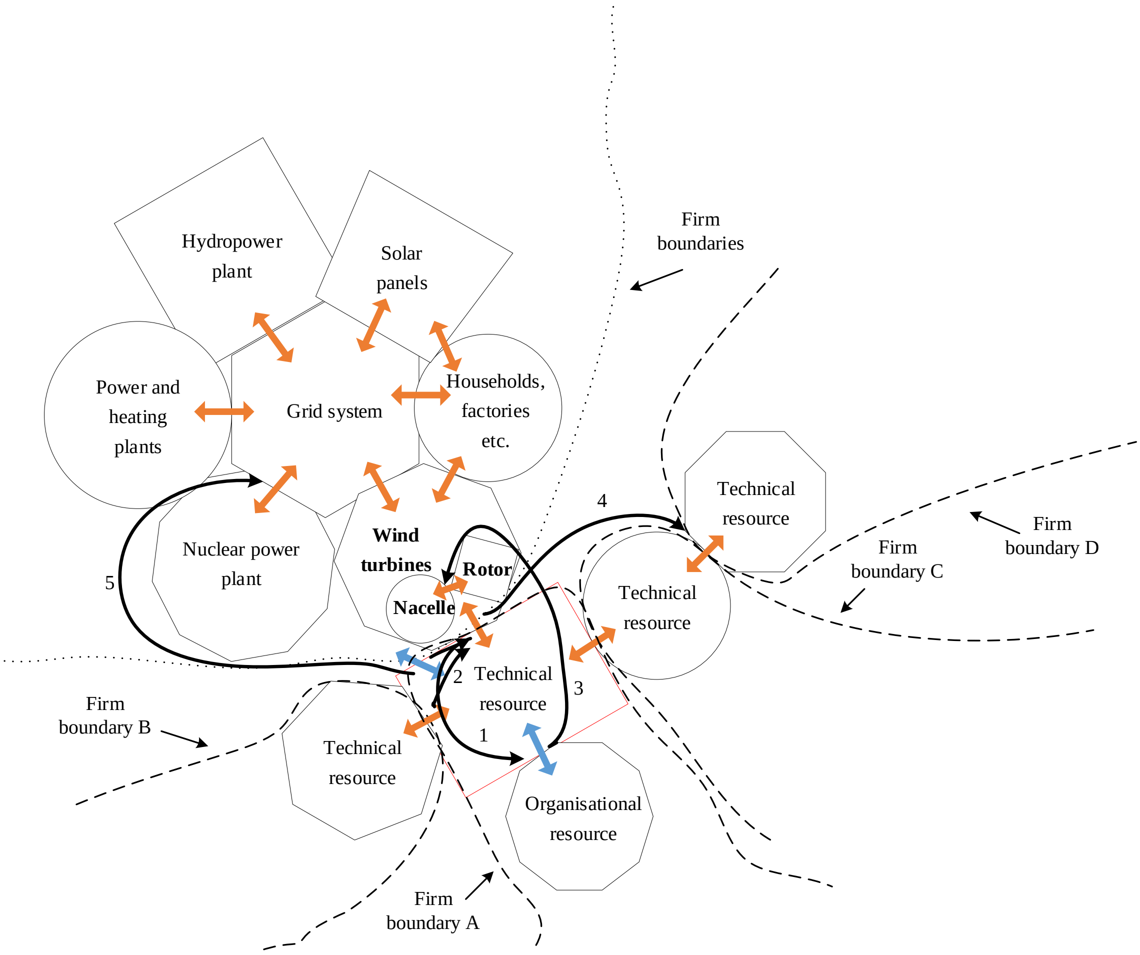


Figure 19. Embedding a technical resource into the resource constellation of wind power

When embedding a technical resource in the resource constellation of wind power, it is important to consider the effect of a technical resource tie interface on a directly connected resource collection interface (1). The wind turbines have certain requirements to fulfil, such as producing enough electricity and not failing as a result of external weather conditions. In the technical resource tie interface between a technical resource such as the wood tower and the turbine, new requirements like the dimensions of the tower and other technical features are revealed. This, in turn, may affect how directly connected organisational resources are developed to meet these requirements. Hence, the mixed resource collection interface between, for example, the master's thesis students and the wood tower may change its features by developing existing tools to calculate certain parameters or hiring new people to conduct new types of calculations.

The creation of a technical resource tie interface between a focal resource and the wind turbine requires several interfaces to interact. To make a technical resource useful in the resource constellation of wind power, it must be adapted to existing industry standards for height and rotor size. Hence, the mixed resource tie interface between the wind power industry's organisational structure and the focal resource is necessary to understanding how the focal resource should be developed. It is important for a resource that is subject to a low degree of exploring versatility to meet industry standards, as it relies on a single application area. However, for a resource subject to a high degree of exploring versatility, other ways may be found for it to be useful, and it will not necessarily depend on just one particular mixed resource tie interface. If a resource is subject to a low degree of exploring versatility and has the potential to be situated in the context of wind power, it is important that other technical interfaces also facilitate the creation of a technical resource tie interface between the focal resource and the wind turbine. One example is the technical resource tie interface between the focal resource and a research facility, which can help develop features of the focal resource that fit well with the wind turbine. Hence, it is important to acknowledge the significance of the interplay between the mixed resource tie interface and the technical resource tie interface when creating a connection to the resource constellation of wind power (2). In the case of the wood tower, for example, the interaction between the wind power industry and the wood tower as well as between RISE's laboratory and the wood tower enabled the technical resource tie interface between the tower and the parts of the wind turbine at the site on Björkö.

Resource collection interfaces will also have a role in determining how a technical resource can be embedded within the context of wind power (3). As an example, the internal resources in the resource collection of the focal resource may reveal resource collection interfaces in which adaptations have been made that in turn will impact how the indirectly connected resource collection interface between the nacelle and rotor will develop. For example, a possible scenario could be that master's thesis students or consultants are able to determine the dimensions of the wood tower according to external factors such as wind and rain, which only work if the nacelle and rotors have certain proportions. The use of wood could be perceived as a feature of the focal resource that not only enables the sustainable production and use of wind turbines but also restricts how it can be used in the resource constellation of wind power. In the case of a resource subject to a low degree of exploring versatility the mixed resource collection interface will restrict only one type of resource collection interface, in this case between the nacelle and the rotors. However, a resource subject to a high degree of exploring versatility may restrict several interfaces in parallel, or only facilitate one in the resource constellation, while at the same time making others less effective.

Another resource interaction pattern that could occur is that related to the network effect of a technical resource tie interface (4). Embedding a technical resource in the resource constellation of wind power means adapting the technical resource's own resource constellation. Hence, the technical resource tie interface between the tower and the turbine parts, such as the nacelle and the rotor, will develop certain features in terms of the design of the tower, nacelle and rotor. This will place demands on the focal resource's own development and production. Consequently, it will require adaptation of not only the production facility in order to produce the technical resource according to certain parameters but also potentially the indirectly connected resource interfaces between the production facility and the part supplier's facility. Hence, four actors may be involved in enabling the production of a technical resource. In the case of a resource subject to a low degree of exploring versatility such as the wood tower, it may be easier to create a close collaboration with a specific supplier and put all the effort into creating a production line that suits this singular purpose. However, having a resource subject to a high degree of exploring versatility and many parallel application areas may place demands on the production facility to adapt to every specific application or force the construction of new facilities.

Learning about current trends in the wind power industry in the mixed resource tie interface between the focal resource and the organisational resources of the wind power industry, and adapting the focal resource accordingly, may affect the indirectly connected technical resource tie interface between the grid system and nuclear power plants. The network effect of a mixed resource tie interface (5) can take the shape of having a mixed resource tie interface that enables the creation of a tall wood tower and large rotors. Consequently, this allows for greater power availability and electricity distribution through the grid system. As the grid system is connected to several other resources in the energy system, consideration must be given to how greater, but still unstable, quantities of electricity should coexist with current electricity distribution. As a result, the indirectly connected resource tie interface between nuclear power plants and the grid system may have to develop new features, such as letting nuclear power plants act as frequency controllers during periods of imbalance in the electricity production and usage. However, the resource structure of nuclear power plants will be exposed to tension as it will have to disconnect existing resources to enable new ways to minimise deterioration of its facility. This is a process that may be both costly and time-consuming.

6.5 A comment on exploring the versatility of a resource in the resource structure of the Swedish energy system

A resource will seldom be useful as a standard product, and as seen in many cases involving innovative products it is subject to adaptation in relation to the resource collections in which it will potentially be used. To realise the potential versatility of a resource, it is important to consider how the resource interfaces in each of the five resource interaction patterns are adapted to each other in terms of modifying or combining a focal resource with another resource to make a new useful resource. As the previous analysis shows, a mix of both is necessary to create a resource that can be useful in the Swedish energy system. Hence, three different ways of bridging to the resource constellations of the Swedish energy system have been identified. Firstly, looking at solar power applications, a component (or a technical resource) may act as a bridge between the resource constellation of the technical resource and the resource constellation of solar power. By combining the focal resource and the component, or more specifically integrating the focal resource into the component, a useful resource can be created that can later be combined with solar panels to make them more efficient. Secondly, when it comes to the wind power application, the analysis shows that a focal resource may be combined directly with the tower's components, such as the nacelle or the rotor. In this sense, the bridge may not exist physically in terms of a component but is created in the technical resource tie interface between the focal resource and the wind turbine's parts. Thirdly, looking at the hydropower application, the technical resource that was about to become part of the resource constellation of hydropower had to be combined with a component before it could become useful in water pipes. Hence, in this case it was also important to have a technical resource that could bridge the two resource constellations. However, in contrast with the resource constellation of solar power and the integration of the focal resource into the component, the component in the resource constellation of water pipes would act symbiotically with the focal resource. Consequently, a bridge would then be realised by allowing the focal resource and component to be physically detached from each other yet combined to make a useful resource.

The creation of a bridge between a focal resource and the resources belonging to the resource constellations of solar power, wind power and micro hydropower may at first seem straightforward. However, as this analysis shows, the resources of the three constellations are strongly interconnected and consequently some will be hard to adapt to enable new resources to access them. One way to capture and predict the outcome of the process of embedding a new resource in a resource structure could be through the resource interaction patterns developed in this study. Based on the previous analysis, it was evident that the indirectly connected resource interfaces may play a significant role in determining how smoothly a new resource can be integrated into a new resource constellation. For example, the resource combinations that make up the grid and water pipe systems are all central to the resource structure of the Swedish energy system, and their resource interfaces have been developed and adapted over many years. In the case of the water pipe system, resources such as households, water towers and treatment facilities need to be considered when trying to embed a new resource in the resource constellation. Hence, it is assumed that it is difficult to rebuild the whole water pipe system to accommodate a new resource, and thus it is important for it to meet existing standards. Moreover, there are difficulties fitting solar panels and wind turbines into the standard operating model to produce a stable amount of electricity to be distributed through the grid system, whereas energy sources like hydropower and nuclear power work well in the system as they and the grid system have both been adapted in relation to each other for a long time. This is close to what Håkansson and Waluszewski (2002a) refer to as a degree of heaviness within the system in terms of difficulties disconnecting, adapting and recombining already combined resources. As Håkansson and Waluszewski (2018) stress, important factors that can influence the heaviness of the system include how long the resources have been adapted to each other and the centrality of the resource combination in the constellation. For example, both the grid and the water pipe systems are typical resources (and combinations) that are central to the Swedish energy system and thus hard to change, as doing so may affect several other resources combined with them.

With regard to the resource structure of the Swedish energy system, it can be argued that heaviness is mostly seen when trying to enter a resource constellation, while being in it is a smooth condition. Consequently, by adapting the wood tower and the micro turbine to the given standards they may work well with the existing resource constellations of wind power and micro hydropower. Hence, there is interplay between the specific resource interface developed between a new resource and the resource that will help bridge it to the system, as well as the resource constellation. The process of embedding a resource in a heavy resource structure may differ depending on the resource constellation concerned and the degree to which the versatility of the resource can be explored. Several new resource interfaces will be explored for resources subject to a high degree of exploring versatility and thus many potential application areas. As a result, many indirect resource interaction patterns will be observable in the resource constellation, and if most of the application areas are aimed at a heavy resource structure like the Swedish energy system, it may be that meeting the industry standards means that some application areas will be restricted. In other words, some indirectly connected resource interfaces may restrict certain trajectories (or interfaces) due to the cost of adapting the existing resources. As Håkansson and Waluszewski (2018) stressed, the ideas will probably develop in a direction that is valuable to the existing heavy resource structure. For a resource subject to a lower degree of exploring versatility the process of embedding it in a heavy resource structure may become smoother as an application area or trajectory is chosen early on. This means that all efforts can be put into adapting the resource interface to those of the resource constellation.

Relating the degree of exploring versatility to the three ways of bridging the resource to a resource constellation, it could be argued that it is possible to directly combine a new resource with those of the resource constellation when it is subject to a low degree of exploring versatility. One example is the wood tower, which developed its interface with the wind turbine in order to become part of the resource constellation of wind power. However, for a resource subject to a high degree of exploring versatility, it is important that it can find use potential through its integration with different components. Instead of modifying the resource to fit each application, and thus the assigned resource constellations, its existing features should be exploited to make it useful as a feature in other existing resources.

7. Concluding discussion and implications

The aim of this thesis is to develop the understanding of resource interaction in business networks based on how start-ups approach the Swedish energy system. The Industrial Network Approach to industrial markets, and specifically resource interaction as a phenomenon in business networks, is taken as a starting point to fulfil this aim. This concluding discussion will start by outlining the theoretical implications of the study and thereafter discuss the implications for the support of start-ups in the Swedish energy system. The chapter will end with a comment on suggestions for further research.

7.1 Resource interaction in business networks

Previous research has shown that technological development and innovation are the result of resource combinations within and across firm boundaries (see e.g. Baraldi, 2003; Holmen, 2001; Håkansson & Waluszewski, 2002a). In order to create a new solution (such as a new useful resource), both existing and new resources need to be combined and function in developing, producing and using settings (Håkansson & Waluszewski, 2007; Ingemansson, 2010). However, difficulties in disconnecting or adapting resources within the existing resource structures of the three business network settings may hinder the process of embedding new resources. Hence, resource structures could be referred to as more or less heavy depending on the degree of required adaptations and the amount of time over which the existing resources have adapted to each other (Håkansson & Waluszewski, 2002a). It is therefore important to understand how existing heaviness can be taken advantage of and how it can both hinder and facilitate the process of embedding a new resource. As Baraldi and Strömsten (2006) stress, in order to capture the value of a resource in relation to the resource structure in which it will be embedded, it is important to study resource interaction at the network level.

Drawing on previous research, this thesis contributes to the understanding of resource interaction in business networks by addressing interaction and the process of embedding new resources in existing resource constellations. Specifically, this study has shown the importance of resource interfaces. Depending on how the features of a resource interface are adapted, other connected resource interfaces will be affected, thus forming several resource interaction patterns in the constellation. By studying how resources interact and changes occur across resource constellations, the thesis contributes to research on resource interaction. It makes three main contributions: firstly, to the concept of resource interfaces and how they are connected in resource constellations; secondly, to the concept of resource versatility and especially the notion of ‘bounded infinite versatility’; and thirdly, it emphasises the importance of considering not only the known use of a resource but also its potential use(s). Each of these contributions is discussed below.

7.1.1 Connected resource interfaces in resource constellations

The first contribution regards the concept of connected resource interfaces. Previous research has described resource interfaces as the contact points at which two resources interact (see e.g. Baraldi et al., 2012; Håkansson & Waluszewski, 2002a; Prenkert et al., 2019). Resource interfaces play an important role as the starting point for resource interaction; they are the contact point through which features are adapted to fit between two resources. Resource interfaces can take different shapes with regard to the type of resources that are interacting, e.g. technical, organisational and mixed (Dubois & Araujo, 2006; Jahre et al., 2006). Moreover, resource interfaces are interconnected, so adaptations in one may affect how another develops. Prenkert et al. (2019) conclude that the more connected a resource is when it comes to having created interfaces with other resources, the more specific and less varied the resource interfaces become. In other words, there is a limitation in how much a resource interface can be developed due to existing connections and the adaptations being made. This is particularly evident for non-standardised resource interfaces.

However, previous studies, including Prenkert et al. (2019), argue that there is a need for further development of analytical tools to study connected resource interfaces and, especially, how to capture connections across resource constellations. This thesis contributes to the conceptualisation of resource interfaces by suggesting an analytical model which captures how resource interfaces are connected and what effects such connections have on resource constellations. By going beyond the previous separation of resource interfaces, which includes technical, organisational and mixed, and considering how they relate to the three functions of the business network (Håkansson & Snehota, 1995), it is possible to study explicitly and in detail the ways in which one resource interface connects to others in the resource constellation.

Based on the suggested conceptualisation of connected resource interfaces, five resource interaction patterns have been identified to support the analysis of the effects of embedding a resource in a constellation. Accordingly, these interaction patterns can be used as analytical tools to understand the value of a resource in relation to a constellation by considering both directly and indirectly connected interfaces. This, in turn, can facilitate an analysis of the process of matching the three business network settings by evaluating potential hindrances and enablers in each setting and how they can affect and be affected by connected resource interfaces in other business network settings. Consequently, analysing the settings could help in increasing the proximity of the three business network settings and, as Håkansson and Waluszewski (2018) stress, creating conditions for innovation to survive in the producing and using settings.

7.1.2 'Bounded infinite versatility' as a result of connected resource interfaces

The second contribution regards the concept of resource versatility, which plays a central role in technological development. Every resource has potential versatility that can be realised through its interaction with other resources. Holmen (2001) points out two ways in which a resource's versatility can be realised: either it can be combined with other resources to create a new useful resource or it can be modified. However, it is important to acknowledge that even though resources can be combined in an endless number of ways, their usefulness is limited by their features. This thesis contributes to previous notions of resource versatility by describing how the process of exploring resource versatility is a matter of exploring and exploiting resource interfaces in a resource constellation.

By taking an analytical starting point in resource interfaces and their connections in resource constellations, the concept of 'bounded infinite versatility' can be further explained as a result of connected resource interfaces that enable or restrict the development of others. By analysing connected resource interfaces in a resource constellation in terms of the five resource interaction patterns, it is possible to evaluate if and how certain resource interfaces in the resource constellation hinder or facilitate the development of other resource interfaces. As the study shows, the higher the degree of exploring versatility of a resource in a resource constellation, the more important it is to approach resource collections that are flexible and willing to adapt.

7.1.3 The importance of considering the potential use of a resource

The third contribution regards the important aspect of *use potential*. Coming back to Holmen (2001)'s question of whether it would be beneficial to define resources in terms of their potential use and value instead of only their known ones, this thesis emphasises the importance of adding *potential use* to the definition of resources. The study illustrates that focal resources are mostly subject to exploring potential uses in interaction with other resources. Hence, by using the existing definition of resources by only considering known use (Håkansson & Snehota, 1995), many 'elements' will be lost and not considered when analysing resource interaction in business networks. It is important to remember that these ‘elements’ may be valuable both for a start-up’s resource collection and for the wider resource constellation. If they are not acknowledged and identified as resources, many new ideas will go unnoticed and not be captured from an analytical point of view.

Exploring potential use of an element is a process that develops over time. Relating this to March (1991)’s concepts of exploration and exploitation they have previously been used in the context of interactive technological development in business networks. For instance, Medlin and Törnroos (2015) stress the importance of seeing the two concepts as verbs and phenomena that unfold over time. Specifically, exploiting an existing business network is essential to enable new resources, activities and actors in business networks to be explored. The authors emphasise that in nascent innovation networks it can be expected that exploration is the dominant activity: when goals become clearer exploitation becomes crucial. On the one hand, it is a matter of exploring a future phase and business network and, on the other, exploiting the current business network with the aim of developing technology and undertaking new exploratory activities. Similarly, this thesis emphasises the two concepts as verbs that take place in interaction. However, by using the concepts at a resource level it is possible to add new insights into how actors search for resources and later adapt their resources to explore and exploit them in the business network.

7.1.4 Analytical generalisation

The above-mentioned theoretical contributions have all been developed by studying the process of embedding focal resources into the resource structure of the Swedish energy system. The ambition relies on analytical generalisation in terms of identifying underlying mechanisms that can help in explaining technological development and innovation in business networks (Easton, 2010). By studying the case of ‘Starting up in the Swedish energy system’, and specifically the interactive processes involved in developing new renewable energy technologies, it was possible to identify five resource interaction patterns that support the analysis of resource interaction and the process of embedding them in business networks. These findings can be of value not only to the context of the Swedish energy system but also to other types of industrial systems. However, it is still of interest to come back to the empirical setting and see what can be learnt from the previous analysis on the processes of starting up in the Swedish energy system. Thus, the next section deals with how to support start-ups in the Swedish energy system.

7.2 Implications regarding how to start up in the Swedish energy system

The processes of starting up in the Swedish energy system are concerned with combining resources. By taking the Industrial Network Approach as a starting point, and thus applying a network perspective to the technological development process, this study shows that starting up in a heavy resource structure requires interaction between several actors in the business network (Aaboen et al., 2017; Ciabuschi et al., 2012). In addition, the study shows the importance of matching what Håkansson and Waluszewski (2007) refer to as the three settings of the business network: the developing, producing and using settings. Any focal resource needs to become embedded in all three settings. However, difficulties may arise, particularly in the using and producing settings due to the heaviness of the system, i.e. previous resource interaction between established actors having resulted in resource adaptations. In other words, the difficulties involved in adapting the focal resource, resource interfaces and/or connected resource interfaces and moving from an explorative focus to exploiting resource interfaces in the resource constellation make embedding new resources difficult.

The study shows that in order to take advantage of the resource structure of the Swedish energy system, a start-up can choose to aim for a lower degree of exploring versatility for example by adapting to industry standards from day one to develop an application with a specific potential user. Working with a reference customer to develop an application area may be fruitful when it covers a large customer segment or leads to another application area that is more closely aligned with customers' needs. As Laage-Hellman et al. (2018) point out, the first application area is a strategic choice that may lead to other collaborations and thus in itself act as a network boundary. Moreover, in order to start up in the Swedish energy system it is important to make use of existing resources. Hence, it is not always possible to embed a resource in its 'original state', its versatility needs to be realised through modification or by combining it with other resources (Holmen, 2001).

One way to formulate a conception of approaching the Swedish energy system could be in terms of a 'bridge' between a focal resource and the resource constellation belonging to a certain part of the energy system. This study suggests that a 'bridge' can take three different forms. Firstly, it can be a component (or technical resource) of which the focal resource will become a part and thus create a new useful resource that can be embedded into the resource structure of the energy system. Secondly, it can be created in the resource tie interface between the focal resource and the resources belonging to the structure of the energy system by modifying the features of the two resources. Thirdly, it can be created by combining a focal resource with a technical one, however instead of integrating the focal resource with a component, like in the first ‘bridge’, the two resources work together but physically detached from each other.

To add to previous research on how renewable technology can enter the energy system (Andersson et al., 2018; Mignon & Bergek, 2016), specifically how start-ups can bring new innovation into the system, it is of utmost importance to assess resource constellations when investing in new innovations. When investing in innovations that come from start-ups, scrutiny of the amount of time and effort that needs to be invested *by the network* to embed the new resource is needed. Specifically, assessments of the following key issues are essential: (1) how the mutual adaptations between the start-up and other actors in the business network will work out, (2) the heaviness of the system in terms of the existing resource structures that can both hinder and facilitate the process of integration, and (3) the interplay between vital resource interfaces necessary to embed a resource into the system.

As the Swedish Energy Agency stresses, it is important to have an industrial partner already on board when applying for financing to show legitimacy. However, based on the findings of this study, it is also important that this industry partner plays a central role in ‘opening up’ the system for the new firm. An industrial partner should contribute legitimacy by showing how it (and its resource collection) can act as a link to a system. Hence, the industrial partner should have a resource collection that is built of resources that can be ‘bridges’ to the system.

In order to transform the Swedish energy system, it is important to avoid forcing innovations to take a certain path because of its economic benefits, which Håkansson and Waluszewski (2018) highlight as common in heavy systems. This study has shown a clear example of an innovation, the algae, that stretched the boundaries of what is possible thanks to the tireless hunt for engaged collaboration partners and a network that could be willingly adapted. These partners were not found amongst established energy companies but those with shared visions and mutual organisational structures. To enable these kinds of radical innovations to take place in the energy system it is therefore important to invest in the partners that will partake of them and help the start-up’s establishment. These partners may be other start-ups or firms that have no previous connections to the energy system. Consequently, instead of investing money in many start-ups it could be preferable to invest in only a few, as well as in their networks. There is a need to create an understanding of different application areas and the actors related to their development, production and use, even though the energy sector is the long-term focus for development.

The managerial implications for start-ups regard the perception of their products, or product ideas, as resources to fit into a structure that is typically characterised by strong connections between resources. They need to be shaped together with potential customers, suppliers and developing partners early in the product development process to enable the transition from an idea to an innovation and then product commercialisation. The process is context specific, as seen in the three start-ups' journeys, however a general recommendation is to seek out partners that are willing to interact and potentially adapt their facilities and equipment. Furthermore, it is highly important to understand the context that a start-up will try to enter, especially how its specific innovation will affect not only the customers' processes but also those of customers' customers.

Finally, as Negro et al. (2012) stress, it is important to bring start-ups to the table and let them be part of policy discussions. The process of finding proximity between the developing, producing and using settings is more challenging for a start-up with no initial business relationships than for an established firm that can build on existing business relationships. This needs to be acknowledged when new policies are created to support the transformation of the energy system.

7.3 Further research

This study shows that resource interaction in business networks starts in the resource interfaces and their connections, which in turn form various resource interaction patterns. In this study, start-ups' efforts to embed their resources into the resource structure of the Swedish energy system have been used as a means to study the phenomenon of resource interaction in business networks. For further research, it would be interesting to analyse the resource interaction patterns in other contexts (or systems) in order to learn more about how connected resource interfaces can both facilitate and hinder the process of embedding resources. Moreover, it would be of interest to continue exploring the potential use of a resource in resource constellations. How can the potential use of a resource, in contrast to its known use, be captured?

In this study, each of the five resource interaction patterns has been analysed separately. A suggestion for further research would be to consider the sequences in which they occur. Does one pattern lead to another, and if so is it possible to predict the order of the patterns? Furthermore, connecting potential sequences to the characteristics of a resource constellation in terms of its flexibility, that is its openness for changing resource interfaces to let new resources in, can help in understanding if a certain sequence may occur in a certain type of resource constellation. Knowing more about those patterns will help in estimating the effects of embedding new resources into a resource constellation more accurately, which in turn will be vital when addressing the transformation of heavy systems.

This study shows the importance of matching what Håkansson and Waluszewski (2007) refer to as the three settings of the business network. For further research, it would be interesting to study the developing, producing and using settings, in the context of the energy system, in more detail. Further research could uncover both the opportunities and difficulties of the settings that are important from the perspective of a start-up approaching the system. In addition, start-ups may be categorised, and based on this supported, in terms of their strong and weak characteristics in relation to the three settings.

As this is an initial attempt to capture the resources of the energy system there are many possibilities to dig deeper and focus more or less closely on various parts of the resource constellations of the energy system. For example, in this study, parts of the energy system, such as the grid system and nuclear power plants, have been considered as single resources. One suggestion for further research, to create a better understanding of how resources become embedded into the Swedish energy system, could be to look into these parts of the energy system in more detail, i.e. analyse the introduction of new technology at the resource-structure level. This in turn may help in exploring the effects of embedding new resources into the energy system.

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Appendix

An example of an interview guide used during an interview with the CEO of Aqua Robur, which took part 13/05/2016. The interview guide is translated from Swedish to English.

A flashback:

- During the autumn 2015 the three inventors came to you with an idea
  - What kind of idea was it?
  - In what way was it connected to the inventor's previous workplace?
    - Who worked there?
    - Was it ok to just take the idea and later patent it?

- I listened to a presentation by one of your board members on twitter where he presented the application area of using the turbine in cities. He mentioned that the inventors considered this application early on, however, as I understood the turbine was first aimed towards natural water streams.
  - Which were the potential customers for the initial application area of natural water streams?
  - What factors influenced the change towards the new application area? Who was involved?
  - Was it the same idea but just in a new context?

- When did you initiate contact with Kretslopp och Vatten? Was it during the shift from the context of natural water streams to cities? Or when you shifted from the first-generation prototype to the second-generation prototype (towards supplying electricity to measurement devices)?
  - In what way impacted the visit at Kretslopp och Vatten your new direction? Did the collaboration influence the power range?
  - How did you develop the on-grid/off-grid solution?
  - How did you proceed with the first prototype tests together with Kretslopp och Vatten during spring 2015?
    - Who was involved?
    - Where were the tests conducted?

- How did it go with the collaboration with NTNU?

- A decision was made by the board in May 2015 regarding the development of a new product
  - Which product was this and how has it changed until today?
    - Did it include the off-grid solution?
    - Why did you see a problem with the old solution?
    - When did you start talking about 'Aqua Robur Site'?
    - In what way did the scope of innovation put spanner in the works?

- You hired master thesis students to develop the product. When during the product development phase did they start working with the product?

- How do you distinguish 'Aqua Pro Site' from 'Aqua Pro Shark'?

- You wrote an application to Vinnova together with Kretslopp och Vatten before Christmas and you got the money.
  - What is the aim of this project?

- How does your relationship with Kretslopp and Vatten look today?
  - Is it possible to get contact information to someone who has been involved in your testing of the development of the product?

- How does the ownership look today?

- Did you receive money from Din El's miljöfond?

Using setting

- Who are the potential users of the turbine?
  - When is it planned to reach the market?
  - How have you contacted potential users?

Developing setting

- What other actors are involved in developing the product?
- Regarding the company developing measurement devices, are they developing the product too? How?

- In what way are other Sewage companies involved in developing the product?

Producing setting

- To follow up your email: Who are the potential suppliers to supply parts?
    - Are you in contact today?
    - Are these 3D-printing company, liquid injection moulding company?
    - Will you produce any parts yourself?