Towards shared refrigeration in Dutch industrial parks

Master thesis by
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Towards Shared Refrigeration in Dutch Industrial Parks

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If you want to go fast, go alone
If you want to go far, go together

- African proverb

You need cooling
Baby I’m not fooling

- Led Zeppelin

Dedicated to Shashank

Executive summary

Refrigeration is an important aspect of the industrial world. As worldwide demand for it is growing while environmental issues are being increasingly addressed by regulations, the call for more sustainable practices in the refrigeration fields becomes louder and louder. Currently, refrigeration systems are mostly fragmented, each business having its own set of equipment. This brings along several drawbacks, such as inadequate maintenance, absence of waste heat reusal, high investment costs, and a tendency of especially SMEs to prefer installations with synthetic refrigerants which are cheaper to acquire, but which are more harmful to the environment in case of leakage, and less efficient in operation.

A solution can be sought in "shared refrigeration systems", a form of utility sharing and industrial symbiosis where a central refrigeration plant distributes cold refrigerant via a network of piping to individual companies. This concept has been poorly explored, and the current research aims to investigate the barriers and enablers that are in place for a potential implementation of this shared refrigeration technology among SMEs in Dutch industrial parks, as well as to investigate how the barriers can be overcome. The research is guided by the research question: *"How can the implementation of shared refrigeration among SMEs in Dutch industrial parks be facilitated*?". Data was collected by means of explorative semi-structured interviews (N=13). A preparatory round of interviews (N=3) was added to create a consolidation of the shared refrigeration concept as a reference to ensure the quality of the main interview round.

The results show that there is a range of barriers in place for an implementation of shared refrigeration in Dutch industrial parks: (i) a funding gap in the initiation phase, (ii) the long investment horizon, (iii) uncertainty due to a lack of financial and sustainable assessments, (iv) lack of prior experiences, (v) incapability of local business associations, (vi) inadequate information sharing, (vii) a lack of public awareness, (viii) a fear of being dependent, (ix) a fear of competitive threats, (x) scarcity of implementation opportunities, (xi) strict policies for complementary systems, and (xii) businesses having a short-term focus. Enablers that were identified are: (i) the currently favorable policy climate, (ii) congestion problems in the electricity network, (iii) the currently favorable investment climate, and (iv) active knowledge sharing by governments and consultancy firms.

The research has led to the conclusion that the implementation of shared refrigeration among SMEs in Dutch industrial parks can be facilitated by combined efforts of governments, businesses and academia. Facilitation strategies include conducting scans for opportunity identification, conducting business case analysis to come to financial and sustainable ramifications, closing the funding gap in the initiation phase, disseminating experiences from similar projects, and setting up and/or strengthening the capabilities of local business associations through knowledge sharing and creating partnerships with governments, consultancy companies and research and education institutions. A short overview of the most relevant barriers and strategies to overcome them can be found in Table 6.6.

Keywords: shared refrigeration, utility sharing, industrial symbiosis, SME, sustainability

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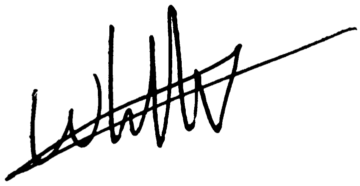

Delft, January 2022

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List of abbreviations

BENG	Bijna Energieneutrale Gebouwen
CEO	Chief Executive Officer
CFC	Chlorofluorocarbon
CO_2	Carbon dioxide
COO	Chief Operating Officer
COP	Coefficient of performance
CTO	Chief Technical Officer
EIP	Eco-industrial park
GCC	Gulf Cooperation Council
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbon
IS	Industrial symbiosis
MLP	Multi-level perspective
MOT	Management of Technology
NH_3	Ammonia
SDE++	Stimulering Duurzame Energieproductie en Klimaattransitie
SME	Small- or medium-sized enterprise
TRL	Technology Readiness Level
VEKI	Versnelde Klimaatinvesteringen Industrie

1 Introduction

Refrigeration is an important and growing aspect of the industrial world. Approximately 10% of all electricity worldwide is used for space cooling (peaking to an astonishing 70% of electricity being used for space cooling during peak hours in the United Arab Emirates and Kuwait), and the demand keeps growing (Eveloy & Ayou, 2019). The high energy consumption, environmental concerns, and high investment costs that go hand in hand with this growing demand for refrigeration pose serious challenges to the industrial world all across the globe. This thesis explores barriers and enablers related to sharing refrigeration equipment in Dutch industrial parks, which might be a potential solution to several of these challenges.

1.1 Problem description

According to a field expert, refrigeration equipment is largely fragmented, meaning that most companies with a need for space cooling have their own individual set of refrigeration equipment (Participant 1A[1], personal communication, April 15, 2021). Many of these existing installations are poorly maintained, and defects and leaks occur on a regular basis[2] (Participant 1A, personal communication, April 15, 2021). He notes that the large degree of fragmentation makes maintenance less efficient and more complicated. The same applies to enforcement of laws and regulations. Another consequence of this fragmentation is that there is limited potential to reuse waste heat generated by the cooling installations (e.g. for district heating). Currently, most installations do not reuse waste heat, and simply emit it into the atmosphere (Participant 1A, personal communication, April 15, 2021). This entails the waste of large amounts of energy.

Most refrigeration installations currently in use in the Netherlands rely on synthetic refrigerants like hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) (NVKL, 2020). Like the earlier generation of chlorofluorocarbons (CFCs), that were discovered to have a strong ozone-depleting effect (Wigley, 1988), these synthetic refrigerants do harm to the environment in case of leakage as they have a so-called Global Warming Potential (GWP) hundreds to thousand times stronger than CO_2 (Rijkswaterstaat, 2020). Therefore, they too are currently subject to a phase-out scheme under the Montreal protocol that previously arranged the phase-out of CFCs (Mota-Babiloni et al., 2015; Kuijpers, 2017).

Natural refrigerants like CO_2 and ammonia are alternatives to synthetic refrigerants. They are already in use, although the share of machines using them is still relatively small (NVKL, 2020). Natural refrigerants have several advantages over synthetic refrigerants, most importantly because they virtually do not contribute to the greenhouse effect in case of leakage[3] (Lorentzen, 1995;

[1] Participants 1A and 1B are managing directors of a Dutch enterprise that specializes in refrigeration installations for both industrial and private applications. Chapter 4 will elaborate on the participants' role in this research project.

[2] In the Netherlands, leakage occurs generally in 3% of synthetic refrigerant installations, while in some other countries this percentage can be up to 20% (NVKL, 2020).

[3] The GWP of ammonia is zero, and CO_2 has a GWP of 1 (Lorentzen, 1995; Rijkswaterstaat, 2020). However, CO_2 used in refrigeration is generally recovered from waste gasses, making its effective GWP in the refrigeration field zero (Lorentzen, 1995).

Rijkswaterstaat, 2020), and installations using natural refrigerants require about 10% - 30% less energy to operate than those using synthetic refrigerants (Stimular, 2021). In addition, installations using natural refrigerants might financially be more interesting in the long term, because of the increasing scarcity of synthetic refrigerants and the fact that they are being phased out (Rijkswaterstaat, 2020).

Despite these advantages, natural refrigerants tend to bring along a number of safety concerns. The use of CO_2 requires working with high pressures, ammonia is poisonous, and other natural refrigerants are flammable[4] (Lorentzen, 1995). Installations using natural refrigerants therefore tend to require a larger investment, as they require more safety measures. Typically, industrial refrigeration installations that use synthetic refrigerants require an initial investment of hundreds of thousands to millions of euros, which is a relatively sizable investment for SMEs (Participant 1A, personal communication, April 15, 2021). For low capacities, CO_2 and ammonia installations can be another 40% more expensive (Participant 1B, personal communication, April 29, 2021).

This difference in investment size is dependent on the capacity of the desired installation. The higher the capacity, the lower the cost difference. The capacity at which natural refrigerants become financially more interesting than synthetic refrigerants is estimated by a field expert to lie around 100 kW (Participant 1B, personal communication, April 29, 2021). The large initial investment required for relatively smaller-sized installations using natural refrigerants tends to be a reason for especially small and medium-sized enterprises (SMEs) to opt for synthetic refrigerants instead (Participant 1A, personal communication, April 15, 2021). This tendency is strengthened as SMEs typically have limited resources and tend to keep a short term focus (Ormazabal et al., 2018; Domenech et al., 2020; Corder et al., 2014; Holt et al. 2000; Petts et al., 1999).

A solution to these issues faced by industrial refrigeration can be sought in sharing refrigeration systems (Eveloy & Ayou, 2019). Generally, this implies creating a central refrigeration plant, which delivers cold to a number of individual companies through a fluid medium. This is a form of utility sharing and industrial symbiosis. Figure 1 provides a graphical representation of this idea.

In a shared refrigeration system, the outdoor units of the refrigeration cycle are replaced by one large plant that is connected to a refrigeration grid. The actual refrigeration will take place in this large unit after which a refrigerated fluid will be distributed throughout the rest of the network. Companies will only need to be equipped with indoor units, and will be able to retract cold energy from the grid according to their needs. Refrigeration therefore becomes less of a product and more of a service. As mentioned, this concept, which will hereafter be referred to as *shared refrigeration* in Dutch industrial parks, likely offers solutions to the problems faced by the current state of refrigeration technology in the Netherlands mentioned before. Despite its potential advantages, the concept of industrial shared refrigeration is still very underexplored, and has not been implemented on a large scale in the Netherlands. Literature on shared refrigeration initiatives in industrial parks like the concept explained above is very scarce (as will be shown in Chapter 2), and it has not been researched what the barriers for the implementation of shared refrigeration in the Netherlands are. The absence of this knowledge makes it difficult for the technology to gain momentum.

[4] Water is not, but as it has a relatively high freezing point, it is not suitable for many industrial refrigeration systems that are required to cool to subzero temperatures.

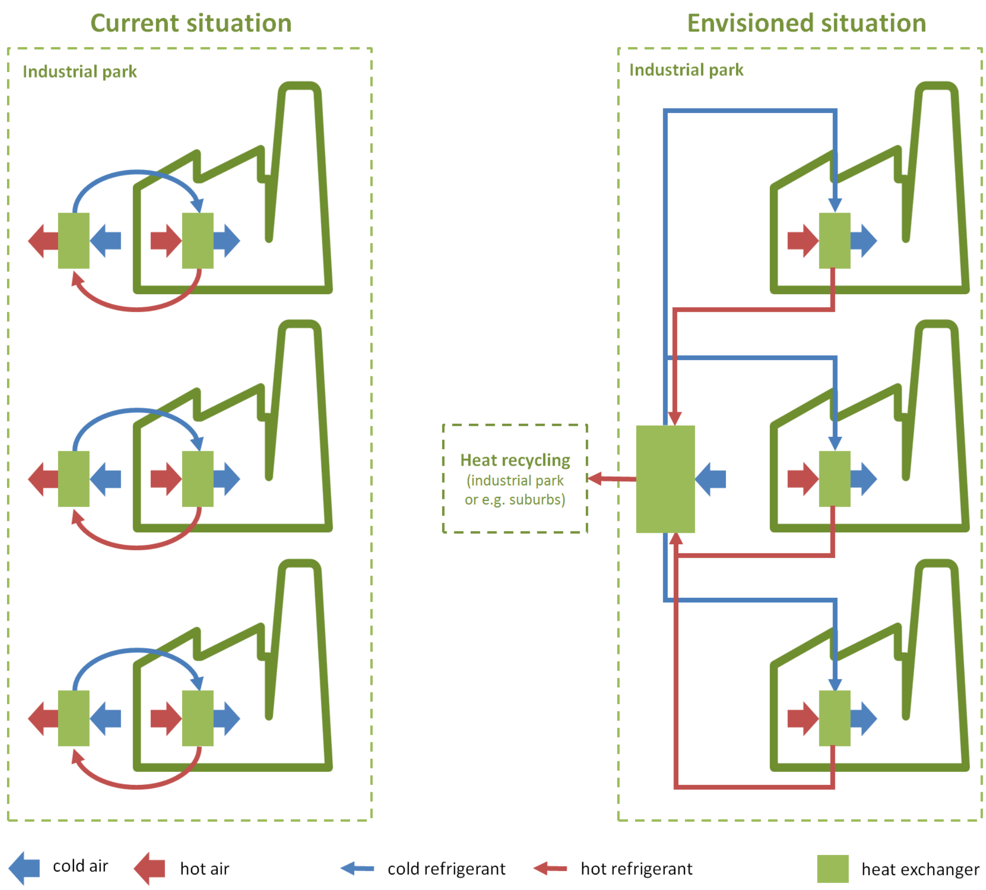

Figure 1.1. Current situation versus shared refrigeration concept.

1.2 Research objective

The current research attempts to shed light on the barriers and opportunities in place for a potential implementation of shared refrigeration in Dutch industrial parks. Data were gathered by means of expert and stakeholder interviews, and were analyzed using the framework for success of industrial symbiosis proposed by Mortensen & Kørnøv (2019). Using their framework, existing contextual factors in the Dutch environment can be compared to those factors that are typically associated with successful IS initiatives, to assess which factors currently form barriers or opportunities. Moreover, the characteristics and envisioned roles and activities of actors in the Dutch context can be compared to those typically associated with actors who are involved in successful IS initiatives. Moreover, a second tailor-made framework was used to assess the presence of barriers that can be present for the engagement of SMEs in industrial symbiosis and eco-innovation. Based on a literature review and expert and stakeholder interviews, the current research attempts to provide recommendations for businesses, governments and academia on how implementation of shared refrigeration among SMEs in Dutch industrial parks may be facilitated. It furthermore evaluates the findings in the light of policy mixes, adoption and diffusion, technological transitions and design dominance.

The thesis has been guided by the following main research question:

RQ How can the implementation of shared refrigeration among SMEs in Dutch industrial parks be facilitated?

To facilitate the research project, the main research question was supported by the following subquestions:

SQ1 Which barriers hamper and which enablers facilitate the implementation of utility sharing and industrial symbiosis among SMEs?

SQ2 Which barriers hamper and which enablers facilitate the implementation of shared refrigeration in Dutch industrial parks?

SQ3 How can the barriers to the implementation of shared refrigeration in Dutch industrial parks be overcome?

1.3 Focus and scope of the research

The current research takes an approach directed at the symbiotic aspect of shared refrigeration. The framework used to analyze the findings is one that concerns critical factors for industrial symbiosis emergence. In the following subsections, the relation of shared refrigeration to industrial symbiosis will be explained. Moreover, the scope of the research in terms of technology and context will be explained.

1.3.1 Relation to industrial symbiosis

Shared refrigeration in industrial parks is a form of *utility sharing*, a term that goes hand in hand with *industrial symbiosis*. Indeed, as the concept entails that waste heat from the refrigeration plant will be reused for valuable purposes, the system can be considered to be a proper form of industrial symbiosis. Industrial symbiosis (IS) is a subconcept of industrial ecology that involves collaboration between different firms to share resources, use each other's waste flows, and engage in other activities that create a more sustainable way of working and foster eco-innovation. Lombardi & Laybourn (2012, p. 31-32) define it as follows: *"[Industrial symbiosis] engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes."*

In the Netherlands, industrial symbiosis, though gaining terrain (Bastein et al., 2013), is currently being implemented on a relatively limited scale. Most of the more extensive symbiotic collaborations take place in eco-industrial parks (EIPs), of which currently several exist in the Netherlands. The Dutch government has stated the aim to transform the country into a fully circular ecosystem by 2050 (Rijksoverheid, n.d.). However, companies remain rather skeptical and oblivious about industrial symbiosis.

Especially companies in the small- to medium-sized range (SMEs) tend to doubt if engaging in symbiotic collaborations will be worth the necessary investments, and fear dependency of unreliable partners and quality issues that might affect their products or services (Rincón-Moreno et al., 2020; Ormazabal et al., 2018). Another issue faced by SMEs is that they are faced by resource and knowledge constraints that lead them to keep to a relatively short-term focus, limiting themselves to their day-to-day business (Petts et al., 1999; Holt et al., 2000; Perez-Sanchez et al., 2003; Lee, 2009; Cecelja et al., 2015). They tend to have little knowledge about environmental issues and have difficulty implementing environmental practices into their activities (Leistner, 1999; Hillary, 2000; De Marchi, 2012; De Marchi & Grandinetti, 2013), often innovating incrementally rather than radically (Brío & Junquera, 2003). In other words - even if SMEs have an interest in improving their sustainability, they need to be encouraged and assisted in actually doing this (Corder et al., 2014).

The benefits of engaging in industrial symbiosis are clear. Research has shown that it generally did not only lead to ecological benefits, but also to profit increases and a better social reputation (Corder et al., 2014; Van Leeuwen, Vermeulen & Glasbergen, 2003). In addition, it has been shown that collaboration between SMEs actually helps the companies build competitive advantage and sustainability (Porter, 1998; Daddi & Iraldo, 2015; Daddi, Nucci & Iraldo, 2017; Prieto-Sandoval et al., 2018).

1.3.2 Technological scope

Utility sharing in a way comparable to the concept of shared refrigeration is not new. The past decades have seen the advent of *district cooling*. The concept of centralized cold generation offers many advantages, such as lower unit cost of cooling, greater efficiency, flexibility, peak-period saving potential, easier maintenance at lower costs, greater sustainability, and space savings for users (Eveloy & Ayou, 2019). It has been applied often in combination with district heating or other forms of utility sharing. However, as will be shown in the next chapter, existing district cooling systems typically use water as a coolant and do not reach subzero temperatures, setting them apart from the concept of shared refrigeration for industrial purposes.

Nevertheless, the necessary infrastructure and inter-organizational relationships show similarity with those in the concept of shared refrigeration. Therefore, lessons learnt from current, past and future initiatives involving industrial district cooling may be valuable for the new concept - especially as subzero shared refrigeration has been studied very limitedly to not at all (as will be shown in the next chapter).

The concept as defined in this master thesis does not necessarily limit itself to a certain type of refrigeration process. Industrial installations using natural refrigerants that are being applied in practice are almost exclusively CO_2 or NH_3 vapor-compression installations (Participant 1A, personal communication, July 6, 2021). Other possible eco-friendly principles of refrigeration are *absorption refrigeration* and *adsorption refrigeration* (generally referred to as *sorption refrigeration*), which are powered by heat rather than electrical energy. However, sorption refrigerators require an even higher investment than traditional vapor-compression installations, and they have a lower coefficient of performance (COP), making them less efficient (Lima et al., 2021). Moreover, Eveloy & Ayou (2019) concluded from an extensive review that sorption refrigeration systems that are currently available, although having potential for future success, require more development to be technically suited for use in district cooling.

For these reasons, it was assumed for the purpose of the current research that the principle of refrigeration is that of vapor-compression refrigeration. However, the research does not exclude principles of refrigeration that might prove to be effective under certain circumstances, like sorption refrigeration (that might be interesting when much waste heat is readily available), vapor-compression/sorption hybrids, or cascade refrigeration (when there is a need for refrigeration to ultra-low temperatures). The proposed solution principle can be applied to all these refrigeration types, as the actual refrigeration only takes place in the central unit.

1.3.3 Geographical scope

The focus of this research is the situation in the Netherlands. However, international factors that might influence a potential implementation of shared refrigeration are taken into account where appropriate.

1.3.4 Focus on SMEs

This research focuses predominantly on SMEs as potential partners in shared refrigeration. This is due to several reasons. Firstly, large companies tend to require more refrigeration capacity, which makes installations using natural refrigerants financially more interesting to them (as mentioned in Section 1.1, these installations are financially more attractive than installations using synthetic refrigerants at higher capacities). Secondly, as the installations are larger and managed by one company, maintenance can be arranged more efficiently and a waste heat coupling is easier to realize. Moreover, larger companies tend to have a longer-term focus and more resources to spend on innovation. Therefore, the potential environmental and financial gains offered by shared refrigeration are significantly smaller if applied to larger companies than if applied to smaller companies. Therefore, this research focuses on small- and medium-sized companies (SMEs).

1.4 Practical relevance

Assessing the barriers and barrier removal is an important step in the emergence of industrial symbiosis initiatives. Grant et al. (2010) propose that, after a new opportunity is identified, *opportunity assessment* is the next step towards a successful implementation of industrial symbiosis. Barrier assessment is a form of assessment that is particularly helpful in early stages of the assessment phase. It “identifies challenges to realization by assessing market, political, social, environmental, financial, and technical feasibility” (Grant et al., 2010, p. 746). The step is inherently linked to the next, which is *barrier removal*. These steps are necessary in order for successful industrial symbiosis to be established.

This research is practically relevant for small and medium enterprises that face large initial investments for refrigeration equipment. These installations can cost up to millions of euros and are regarded as a “necessary evil” by entrepreneurs, because they do not directly lead to profits. Several informal conversations with entrepreneurs in the food industry quickly revealed that there seems to be much enthusiasm for a new system in which such initial investments can be omitted (or significantly reduced), and businesses can withdraw cold energy from a refrigeration grid per kWh.

Moreover, the research is relevant to municipal, regional and national governments in the Netherlands and beyond, as it sheds light on a potential new opportunity to increase sustainability performance. Shared refrigeration will potentially be financially interesting for governments as well, as the subsidies currently given to individual cooling installations can be replaced by a single investment. However, more research will be required to analyze the financial benefits in detail, as this is not the scope of the current research.

In general, the main practical relevance of this research lies in that it sheds light on the feasibility and sociotechnical viability for the envisioned system of shared refrigeration in Dutch industrial parks, and recommends ways to facilitate its practical implementation.

1.5 Scientific relevance

The research is scientifically relevant as it concerns a future technology that has not been applied yet in practice. There is no dedicated literature about the barriers faced by shared refrigeration in Dutch industrial parks, nor is there dedicated literature providing advice to overcome these barriers. This research attempts to fill these knowledge gaps, and build a foundation on which future research and design can build.

Not only is it relevant to the scientific field of refrigeration technology, it also offers new insights to research concerning district cooling and other forms of district energy initiatives, as the barriers faced by shared refrigeration will likely be applicable to other initiatives that have similar designs and require similar organization practices. The research also contributes to the general literature of industrial symbiosis and eco-industrial parks, as it paves the way for a new type of symbiotic relationship that may be developed between companies, based either at normal industrial parks or at eco-industrial parks. Most notable, the study contributes to the relatively small scientific field that occupies itself with the investigation of SME involvement in sustainable innovation and industrial symbiosis. Much existing literature in these fields focuses on the behavior and practices of larger companies, while SMEs are usually given secondary importance. The current research attempts to enlarge the knowledge base about their behavior and opportunities. As SMEs comprise a large part of worldwide businesses, much potential lies in the engagement of these companies in sustainable practices.

Finally, the study aims to create linkages to other scientific fields like policy mixes, adoption and diffusion, sustainable transitions, and design dominance, as to increase the understanding of the mutual implications these fields of study have on each other, and most notably shared refrigeration and other utility sharing and industrial symbiosis initiatives. Recommendations derived from this study will provide future researchers with pursuable leads to advance these scientific fields further in the direction of sustainable collaboration, eco-innovation and industrial symbiosis.

1.6 Study programme relevance

Concerning the relevance with respect to the Management of Technology programme, what makes a thesis an MOT thesis is summarized in the following quote: *"Management of Technology graduates learn to explore and understand how firms can use technology to design and develop products and services that contribute to improving outcomes, such as customer satisfaction, corporate productivity, profitability and competitiveness."* (TU Delft, n.d.-a).

This thesis project explores the potential of shared refrigeration and attempts to understand how stakeholders can implement and utilize the technology to improve efficiency, profitability and sustainability. The thesis project will contain several analytical components, such as a stakeholder analysis and an analysis of stakeholder interviews. It will take into account both technical and social aspects of shared refrigeration. The thesis project will provide an exploratory study of managerial aspects in a technological context. It will employ research methods as taught in the MOT curriculum. Therefore, this thesis complies to all requirements of an MOT thesis, and can be considered as such.

1.7 Thesis structure

This report commences with a review of relevant literature in Chapter 2, after which the employed methodology is explained in Chapter 3. Chapter 4 will explain the process by which the concept of shared refrigeration was consolidated. Chapter 5 elaborates on the main interview round and provides its results, after which Chapter 6 provides a discussion of these findings. A conclusion to the research is provided in Chapter 7, after which the report is concluded with recommendations for future research, and practical efforts in Chapter 8, as well as a reflection on the study trajectory.

2 Literature review

This chapter provides a literature review of the problem area, in order to consolidate the knowledge gaps that this thesis attempts to fill. The literature that was reviewed was selected according to a process that is explained in Section 2.1. Section 2.2 provides a review of the selected relevant articles, followed by the identification of the knowledge gaps in Section 2.3, and a review of theoretical frameworks to guide this thesis in Section 2.4.

2.1 Search process

This section describes the search process, elaborating on the scientific fields from which literature was drawn, as well as the search terms that were used and the selection criteria by which relevant articles were filtered out.

2.1.1 Scientific areas

2.1.1.1 Shared refrigeration and district cooling

As the topic of the current research is shared refrigeration, the first step in searching for relevant literature entails searching for articles on this specific topic. As it turned out, there were no relevant articles that concerned the concept of shared refrigeration. Therefore, the scope of the literature review was extended to include the technology of district cooling, which is similar in structure as shared refrigeration, but differs on certain points as explained in Section 1.3.2.

2.1.1.2 Industrial symbiosis

As explained in Section 1.3.1, the concept of shared refrigeration system can be considered to be a proper form of industrial symbiosis. Therefore, it was deemed valuable to extend the search to include factors faced by SMEs engaging in industrial symbiosis.

2.1.1.3 Eco-innovation

In addition to the previously mentioned areas, the field of eco-innovation was also expected to contain useful literature for the purposes of this research. Eco-innovation is defined as “all measures from relevant actors that introduce, develop, and apply new ideas, behaviors, products and processes and contribute to reducing environmental burdens or ecologically specified sustainability targets” (Rennings, 2000, p. 322).

2.1.2 Search terms and selection criteria

Table 2.1 displays the results of the keyword search for articles related to shared refrigeration and district cooling. All searches were conducted in Scopus. The total numbers of hits per search are displayed in the table, followed by the number of articles that were found relevant (displayed in parentheses). During the search, it was discovered that some search terms yielded very few results. Therefore, some variations of search terms were used in order to avoid missing out on relevant articles. Moreover, an approach of inverse funneling was used in the search process. At the start of the search process rather narrow search terms were used which resulted in relatively few search results. Therefore, the search was reiterated using increasingly broader search terms, to allow the discovery of a wider range of articles. In this iterative process, cues from titles and abstracts of already found articles were used to improve the quality of the search terms and to align them with relevant jargon. Articles that were found relevant were also scanned for relevant references to other articles (this practice is commonly referred to as “snowballing”).

To determine which of the found articles would be relevant, the titles and abstracts were scanned manually for each article. In determining which articles were potentially relevant, the following selection criteria were used. These criteria were determined partly in advance, and partly during the search process, after the nature and contents of the search results became more evident.

For articles concerning shared refrigeration and district cooling:

1. Articles not related to any aspect of utility sharing, industrial symbiosis, eco-innovation or other fields related to sustainable innovation were <u>not</u> taken into account.
2. Articles dealing with shared refrigeration or district cooling initiatives for industrial purposes were taken into account, whereas articles that do not involve industrial applications were <u>not</u> taken into account.
3. Articles containing aspects of management and organization of district cooling systems were taken into account, whereas articles dealing only with technical aspects of these systems were <u>not</u> taken into account.

For articles concerning engagement of SMEs in industrial symbiosis:

1. Articles that provided insight into factors influencing engagement of SMEs in IS were taken into account.
2. Reviews of potential IS opportunities were <u>not</u> taken into account.
3. Case studies were taken into account.
4. Reviews of results accomplished by IS were <u>not</u> taken into account.
5. Literature reviews, reviews of tools for promoting IS, and more general findings about IS, EIPs and the circular economy were taken into account.
6. Articles that describe technological design processes of IS tools were <u>not</u> taken into account.

For articles concerning engagement of SMEs in eco-innovation:

1. Articles that provided insight into factors influencing engagement of SMEs in eco-innovation were taken into account.
2. Reviews of potential eco-innovation opportunities were <u>not</u> taken into account.

Table 2.1. Keyword search results for shared refrigeration and district cooling.

Field	Search terms	Hits
Shared refrigeration and district cooling	TITLE-ABS-KEY ("shared refrigeration")	0 **(0)**
	TITLE-ABS-KEY ("district refrigeration")	1 **(0)**
	TITLE-ABS-KEY ("central refrigeration" OR "centralized refrigeration")	54 **(0)**
	TITLE-ABS-KEY ("district cooling" AND refrigerat*)	53 **(2)**
	TITLE-ABS-KEY ("refrigeration grid")	0 **(0)**
	TITLE-ABS-KEY ("industrial symbiosis" AND refrigerat* OR cooling)	25 **(0)**
	TITLE-ABS-KEY ("utility sharing" AND refrigerat* OR cooling)	1 **(0)**
	TITLE-ABS-KEY ("district cooling" AND industr*)	78 **(2)**
	TITLE-ABS-KEY ("district cooling" AND barrier*)	8 **(2)**
Engaging SMEs in industrial symbiosis	TITLE-ABS-KEY (“industrial symbiosis” AND (foster* OR cultivat* OR encourag* OR stimulat*))	125 **(14)**
	TITLE-ABS-KEY (“industrial symbiosis” AND (sme OR smes OR (small* AND medium* AND (entreprise* OR enterprise*))))	35 **(7)**
	TITLE-ABS-KEY ((eip OR eips OR “eco-industrial park” OR “eco-industrial parks”) AND (sme OR smes OR (small* AND medium* AND (entreprise* OR enterprise*))))	14 **(2)**
	TITLE-ABS-KEY ((eip OR eips OR “eco-industrial park” OR “eco-industrial parks”) AND netherlands)	9 **(4)**
	TITLE-ABS-KEY ((foster* OR cultivat* OR encourag* OR stimulat*) AND (sme OR (small* AND medium* AND (entreprise* OR enterprise*)))) (for articles citing Chertow (2000) or Chertow (2008))	43 **(14)**
	TITLE-ABS-KEY ((foster* OR cultivat* OR encourag* OR stimulat*) AND (sme OR (small* AND medium* AND (entreprise* OR enterprise*)))) (for articles citing Lombardi and Laybourn (2012))	27 **(3)**
Refrigeration in the context of eco-innovation	TITLE-ABS-KEY (("eco-innovation" OR “environmental innovation”) AND refrigeration)	1 **(0)**
	TITLE-ABS-KEY ("eco-innovation" AND cooling)	0 **(0)**
Engaging SMEs in collaborative eco-innovation	TITLE-ABS-KEY (("eco-innovation" OR "environmental innovation") AND (sme OR smes OR (small* AND medium* AND (entreprise* OR enterprise*))) AND (shar* OR collaborat* OR symbio*))	28 **(6)**
Total (relevant)		**56**

2.2 Synthesis

The articles that were found to be relevant in the search and selection process as described in the previous section were analyzed in more detail. This section provides a review of the articles that were found to contain relevant information for the purposes of this research.

2.2.1 Shared refrigeration and district cooling

Relevant articles that related to the specific concept of shared refrigeration were not encountered during the search. Therefore, literature on district cooling was analyzed more extensively. Several researches have investigated the status, challenges and future opportunities for district cooling. They emphasize the benefits of district cooling in terms of energy efficiency, flexibility, operational costs, construction and maintenance costs, reliability and space saving (Rezaie & Rosen, 2012; Palm & Gustafsson, 2018; Eveloy & Ayou, 2019). Eveloy & Ayou (2019) note that district cooling initiatives in the Gulf Cooperation Council (GCC) region have led to energy savings of approximately 46% per year.

However, initial investments to build a district cooling system are generally high due to the need for heavy machinery and extensive distribution network (Rezaie & Rosen, 2012; Eveloy & Ayou, 2019; Vasilev & Unzhakov, 2020), and the required capacity is not seldom overestimated during the design stage (Eveloy & Ayou, 2019). Therefore, there is a risk of under-realization by district cooling systems which causes problems in cost recovery (Eveloy & Ayou, 2019). There are frequent imperfections in the distribution of costs among stakeholders in existing district cooling systems (Eveloy & Ayou, 2019), and there is generally much uncertainty among participants about whether district cooling will be worth the investment and effort (Sernhed, Lygnerud & Werner, 2018). Subsidies on utilities used in traditional technologies, like water and electricity, decrease the financial gains of switching to district cooling (Rezaie & Rosen 2012; Eveloy & Ayou, 2019; Vasilev & Unzhakov, 2020).

Uncertainty among potential partners and investors also comes forth from the fact that district cooling technology has been applied far less extensively than its counterpart district heating (Eveloy & Ayou, 2019; Vasilev & Unzhakov, 2020). Sernhed, Lygnerud & Werner (2018), who researched district cooling initiatives in Sweden, argued that district cooling is subject to inadequate information sharing, a lack of available business models and a lack of financial data. Other researchers have come to a similar conclusion, also arguing that a lack of information sharing is a barrier for the growth of district cooling technology (Palm & Gustafsson, 2018; Vasilev & Unzhakov, 2020). Palm & Gustafsson (2018) note that district cooling initiatives are often launched in collaboration with parties that are already familiar with the technology, and that there seems to be little interest in adapting the information provision to target new user groups.

Governments often do not consider district cooling to be in need of public policy and planning (Palm & Gustafsson, 2018; Eveloy & Ayou, 2019; Vasilev & Unzhakov, 2020). The process of developing district cooling is generally insufficiently integrated to achieve optimal results, which has resulted in suboptimal results in terms of energy use, sustainability and economic performance (Eveloy & Ayou, 2019). Eveloy & Ayou (2019) note that cross-sectorial integrations and synergies involving district cooling still remain largely unexplored. Moreover, there is a lack of local technical codes and maintenance standards, which help establish minimum requirements for quality, reliability and performance (Eveloy & Ayou, 2019; Vasilev & Unzhakov, 2020). Palm & Gustafsson (2018) argue that more collaboration between private and public actors might be an enabling factor for district cooling to be successful.

Another barrier that is faced by district cooling technology is the difficulty finding suitable locations for implementation (Rezaie & Rosen, 2012).

A cautious note must be made about the cited research articles, as some of them focused on specific geographical areas. It is therefore not certain if the same policy problems exist in other regions. Moreover, the region where district cooling is implemented might also affect district cooling design choices, as there will be more demand for cooling in hot areas and less demand in cold areas. Therefore, cases in warm countries might include systems using heat-driven refrigeration technologies like sorption refrigeration, while traditional vapor compression installations might be more efficient in colder climates, where there is more demand for heating.

2.2.2 Engaging SMEs in industrial symbiosis and eco-innovation

2.2.2.1 Industrial symbiosis

Multiple sources note that SMEs are key elements in achieving sustainability goals, as well as vital factors in establishing large-scale IS implementation (cf. Simboli et al., 2014; Sillanpää & Ncibi, 2019). Sillanpää & Ncibi (2019) argue that it is important for large companies and other movements to support SMEs in embracing industrial symbiosis, and give them access to innovative technologies and processes. As SMEs comprise by far the largest part of firms worldwide, they are essential for IS to become common practice.

Ormazabal et al. (2018) analyzed challenges and barriers to implementation of circularity in Spanish SMEs, and revealed that the barriers could be divided into two types: hard barriers and human-based barriers. Hard barriers include insufficient finances or financial incentives, a lack of technological knowledge, and inadequate information systems. On the other hand, human-based barriers involve social factors like leadership and customer (dis)interest in sustainability. Patricio et al. (2018), who carried out a survey among Swedish SMEs, found that “lack of time” and “lack of knowledge” were often mentioned as main barriers to engaging in IS, indicating that businesses may also be in the situation where they have the knowledge to engage in IS, but no time to invest in it.

The same barriers were confirmed to exist by multiple researchers (Corder et al., 2014; Cervo et al., 2019; Domenech et al., 2020; Rincón-Moreno et al., 2020; Turken & Geda, 2020). The research by Ormazabal et al. (2018) included a survey whose results indicated that company leaders were doubtful about the benefits of the circular economy, stating that they thought circularity would not increase their profits and level of sustainability. It was found that the SMEs included in the research kept a rather short-term focus, which limited their sustainability management to complying to legal requirements and saving costs. This is in line with other research (Domenech et al., 2020; Corder et al., 2014; Holt et al., 2000; Petts et al., 1999). Moreover, Rincón-Moreno et al. (2020) indicate that company leaders tend to have concerns about becoming dependent on unreliable partners, or about the quality of the outputs. These different barriers, although relatively limited in number, seem to be important deal breakers for IS emergence.

Building on Peters and Turner (2007), Corder et al. (2014) note that, once an IS network has been initiated, actors tend to put much effort into getting the most out of it. This indicates that the greatest barrier for the engagement of companies in IS networks is the initiation of the process.

However, Lambert and Boons (2002) argued that it is important to make sure that proper management instruments are in place to cope with issues that will almost certainly arise over the years.

The articles that were reviewed deal with the somewhat broad topic of industrial symbiosis in general and do not concern shared refrigeration. They build on a variety of data sources and case studies of an extensive variety of situations (geographical situations, intra- and inter-organizational relationships, waste exchanges, utility sharing, etc.). Despite this diversity of situations, it seems that many researchers identified the same barriers faced by SMEs to engage in industrial symbiosis, irrespective of the individual situations of the cases they studied.

However, it can not be confirmed with certainty that the same barriers will apply to the specific concept of shared refrigeration in Dutch industrial parks. Dedicated research is needed to investigate this.

2.2.2.2 Eco-innovations

Existing research concerning the engagement of SMEs in eco-innovation stresses most importantly that collaborations with other actors has a very beneficial effect on the level of eco-innovation in SMEs (Klewitz et al., 2012; Triguero et al., 2013; Sáez-Martinez et al., 2014; Triguero et al., 2014; Sáez-Martinez et al., 2016; Ha et al., 2021). Collaborations are especially important for SMEs, as those can help strategically spread out risks and uncertainties that are typically associated with eco-innovations (Sáez-Martinez et al., 2016). Klewitz et al. (2012) conclude that collaborations between SMEs, local public bodies, and consultancy firms are most notably beneficial to eco-innovation as they provide SMEs with plenty of guidance and knowledge. Other collaboration partners can be financial institutions, public bodies, other market actors and competitors (Sáez-Martinez et al., 2016; Ha et al., 2021), although collaboration with competitors might also in some cases result in fewer incentives to implement eco-innovations (Ha et al., 2021).

Klewitz et al. (2012) noted that SMEs might consider their own impact on the environment to be negligible, and tend to not often be confronted by other parties to reassess their environmental impact. Sáez-Martinez et al. (2016) argue that firms can become locked in an individual trajectory due to the specific competencies they have developed over time, conservative search routines, and clustering within established regimes, which prevents them from looking out of the box. They argue that this path-dependency can be rather difficult to overcome.

Better environmental awareness and higher level of education among firm leaders increases the firm's eco-innovative performance (Ha et al., 2021). Similarly, Sáez-Martinez et al. (2016) found that firms that are characterized by a high level of knowledge, formal appropriability mechanisms, and good recognition of market opportunity arising from cooperation, are significantly more likely to engage in eco-innovation. Moreover, firms that have already developed a high innovative capacity are more likely to perform better at eco-innovation in the future (Sáez-Martinez et al., 2016). Knowledge sharing is therefore an important factor, although the way in which this sharing is happening has an effect on the successfulness: for example, handbooks or similar sources of codified information were less effective in fostering eco-innovation (Klewitz et al., 2012).

SMEs tend to act rather reactively to sustainable practices, and external stimuli provided by public intermediaries are important triggers for SMEs to engage in sustainable practices (Klewitz et al., 2012). Notably, policies that stimulate networking with other market actors to foster collaborations, adoption of novel technologies, and upgrading a firm's technological capabilities, are beneficial to a firm's eco-innovation performance (Sáez-Martinez et al., 2016). Collaborations between SMEs and universities, apart from fostering any kind of eco-innovation, positively moderate the effect of policy regulations and supply-side factors on the development of eco-innovations (Triguero et al., 2013; Sáez-Martinez et al., 2016). Sáez-Martinez et al. (2016) argue that national governments should encourage these collaborations, as they appear to be more effective than subsidies and tax incentives. Market factors tend to be drivers for less advanced eco-innovation rather than for highly advanced innovation (Triguero et al., 2014), implying that policy instruments make for better drivers for eco-innovation.

2.3 Knowledge gaps

Although there has been some amount of research into the barriers and enablers of district cooling systems and engagement of SMEs in industrial symbiosis and eco-innovation, existing research does not provide dedicated information about barriers faced by shared refrigeration technology in the Netherlands in specific, nor does it provide dedicated advice to remove those barriers. In other words, the following two knowledge gaps can be identified:

Knowledge gap 1: No scientific research has been carried out to identify the barriers faced by shared refrigeration technology in the Netherlands

Knowledge gap 2: No scientific research has been carried out to propose strategies to remove barriers faced by shared refrigeration technology in the Netherlands

The current research attempts to address these knowledge gaps with the help of the research questions introduced in Chapter 1.

2.4 Theoretical framework

To provide structure to the research into the factors determining the implementation of shared refrigeration technology in Dutch industrial parks, a framework is useful. A framework provides a scientific base on which new findings can be structured, and it serves as an instrument of guidance that safeguards the relevance of the data, limits the scope of the research and defines the viewpoint from which the data are analyzed. For the purposes of this research, which focused on what factors determine the success of a new symbiotic technology that has not been implemented yet, a framework was needed which focuses on the factors determining the very first stage of industrial symbiosis implementation. Several frameworks that were found in the literature have been assessed for relevance.

Boons et al. (2017) devised a framework for the implementation of industrial symbiosis that focuses on the dynamics between different actors in initial stages of industrial symbiosis development. This framework is process-based and maps typical pathways by which industrial symbiosis evolves. However, the framework does not put emphasis on barriers and enablers that determine the emergence phase of industrial symbiosis, and focuses more on the development stage that comes somewhat later in the process. Similarly, the framework of Susur et al. (2019) focuses on stages of IS development after the first moves are made, and does not provide structured insight into factors determining IS emergence.

Some articles do focus on very early stages of IS development, but are limited in the sense that they focus on only certain factors. Spekkink & Boons (2016) for example focus on the emergence of collaborations, taking a process-based approach in which they describe collaborations as emerging from certain sequences of events. Their research does not shed light on how these events came about, or which factors determined them. A similar situation can be seen in the framework by Sun et al. (2017), which does focus on early stages but puts its primary focus only on the effect of anchoring on IS emergence.

Articles that do focus on enablers, barriers and other factors determining industrial symbiosis implementation are abundant, but again focus mainly on factors that determine the IS development process after the initial emergence stage (Mortensen & Kørnøv, 2019; Walls & Paquin, 2015; Yu et al., 2014; Chertow, 2007; Doménech & Davies, 2011; Chertow & Ehrenfeld, 2012; Paquin & Howard-Grenville, 2012; Eilering & Vermeulen, 2004).

Yap & Devlin (2017) propose a framework that takes a broader perspective, emphasizing enterprise-related factors and environmental factors more. However, the researchers themselves do not provide a detailed, well-structured framework for factor analysis. Instead, they provide an outline for a framework that includes all phases of IS development, from emergence to disruption. For the purposes of the current research, a framework that is more detailed and structured, and that has a more dedicated focus on the emergence phase, is preferred.

Such a framework is presented by Mortensen & Kørnøv (2019), who created a model providing insight into critical factors for success of industrial symbiosis initiatives, based on a systematic and rigorous review of existing empirical literature. The model focuses on the emergence phase of industrial symbiosis, and sheds light on factors and processes that enable the emergence of industrial symbiosis. It is therefore relevant for actors and stakeholders that wish to start or participate in such initiatives. Mortensen & Kørnøv (2019) developed the framework after identifying that existing frameworks mainly focused on the development of industrial symbiosis initiatives and not sufficiently on the initial emergence phase of industrial symbiosis, and the development of synergistic ties. The framework they developed aims to fill this knowledge gap, in order to shed more light on facilitating the emergence of industrial symbiosis. The researchers divided the emergence process of industrial symbiosis into three phases, which they labeled (i) awareness and interest in industrial symbiosis, (ii) reaching out and exploration of connections, and (iii) organizing. These phases do not have to follow each other linearly, but there might be iterations as the emergence of industrial symbiosis should not be considered a linear phenomenon. In each phase, the authors identified contextual conditions that they found to play a role in the success of IS emergence. They identified key actors and the roles that they tend to take in successful initiatives. They also pointed out the actors' characteristics and activities that are associated with success.

3 Research methodology

This chapter will discuss the research approach by which the research questions were answered. As the concept of shared refrigeration is a relatively unexplored one, there is a need for a tailor-made methodological approach for this research. This chapter will explain the research strategy, the theoretical frameworks, and the research structure.

3.1 Research strategy

Exploratory research is suited for areas where "a) not much is known not much is known about a particular phenomenon; b) existing research results are unclear or suffer from serious limitations; c) the topic is highly complex; or d) there is not enough theory available to guide the development of a theoretical framework" (Sekaran & Bougie, 2016, p. 43). Therefore, as virtually no scientific knowledge of barriers and enablers to shared refrigeration in Dutch industrial parks exists, an **exploratory** approach suits the purposes of this research. Exploratory research methods tend to be flexible in nature and usually rely on qualitative methods of data collection (Sekaran & Bougie, 2016).

Sekaran & Bougie (2016) identify seven types of possible research strategies: (i) experiment, (ii) survey research, (iii) observation, (iv) case studies, (v) grounded theory, (vi) action research, and (vii) mixed methods research. For the purposes of this research, a **survey approach** was deemed most suitable due to the absence of any dedicated scientific data as well as case study possibilities. Within a survey approach, several data collection methods are possible, of which self-administered questionnaires are the most common (Sekaran & Bougie, 2016). However, this type of data collection was deemed too narrow for a field of research that is largely unexplored. For the purposes of this research, **interviews** were deemed the most suitable method of data collection.

Several types of interviews were taken into consideration. Unstructured interviews allow for a broad input by the participants, which can provide valuable insights that structured interviews would not have been able to provide (Adams, 2015; Sekaran & Bougie, 2016), while structured interviews are useful to investigate phenomena that are more established. In this research, models that concern barriers and enablers to industrial symbiosis emergence were applied to a new context. Therefore, a hybrid form of structured interviews (which are useful to validate the models) and unstructured interviews (which are useful to uncover new leads (Adams, 2015)) was deemed most suitable. The interviews therefore had a **semi-structured** nature.

Although face-to-face interviews tend to offer more opportunities to identify nonverbal cues (Sekaran & Bougie, 2016), the participants in this research were given the freedom to choose whether they preferred face-to-face or electronic interviews according to what they were comfortable with, as face-to-face meetings posed potential health risks due to the COVID-19 pandemic.

3.2 Research frameworks

The theoretical framework used to structure this research rests on two pillars: the framework for critical factors for industrial symbiosis emergence as established by Mortensen & Kørnøv (2019), and a list of barriers to engagement of SMEs in industrial symbiosis, which was distilled from scientific literature in the literature review of this thesis. The following sections elaborate on the two pillars, as well as the purpose of the combined approach taken in this research.

3.2.1 Critical factors for industrial symbiosis emergence

The model by Mortensen & Kørnøv (2019), as described in Section 2.4 provides insight into critical factors for success of industrial symbiosis initiatives. The model focuses on the emergence phase of industrial symbiosis, and sheds light on factors and processes that enable the emergence of industrial symbiosis. It is therefore relevant for actors and stakeholders that wish to start or participate in such initiatives. The model is displayed in Figure 3.1.

The researchers divided the emergence process of industrial symbiosis into three phases, which they labeled (i) awareness and interest in industrial symbiosis, (ii) reaching out and exploration of connections, and (iii) organizing. These phases do not have to follow each other linearly, but there might be iterations as the emergence of industrial symbiosis should not be considered a linear phenomenon. In each phase, the authors identified contextual conditions that they found to play a role in the success of IS emergence. They identified key actors and the roles that they tend to take in successful initiatives. They also pointed out the actors' characteristics and activities that are associated with success.

The current research had the objective to find out what barriers and enablers are present for the implementation of shared refrigeration in Dutch industrial parks and how the barriers can be overcome. The framework by Mortensen & Kørnøv (2019) provided a useful model to compare the current contextual situation in the Netherlands to contextual factors that have proven to contribute to successful IS emergence. Moreover, after the stakeholders had been interviewed, their characteristics and their views on their roles and activities in a potential shared refrigeration implementation process could be compared to actor characteristics, roles and activities that have proven to contribute to successful IS emergence according to the framework of Mortensen & Kørnøv (2019). The model could thus serve more or less as a measuring instrument by which light can be shed on to what extent the Dutch context and actors are currently facilitatory to the emergence of shared refrigeration initiatives.

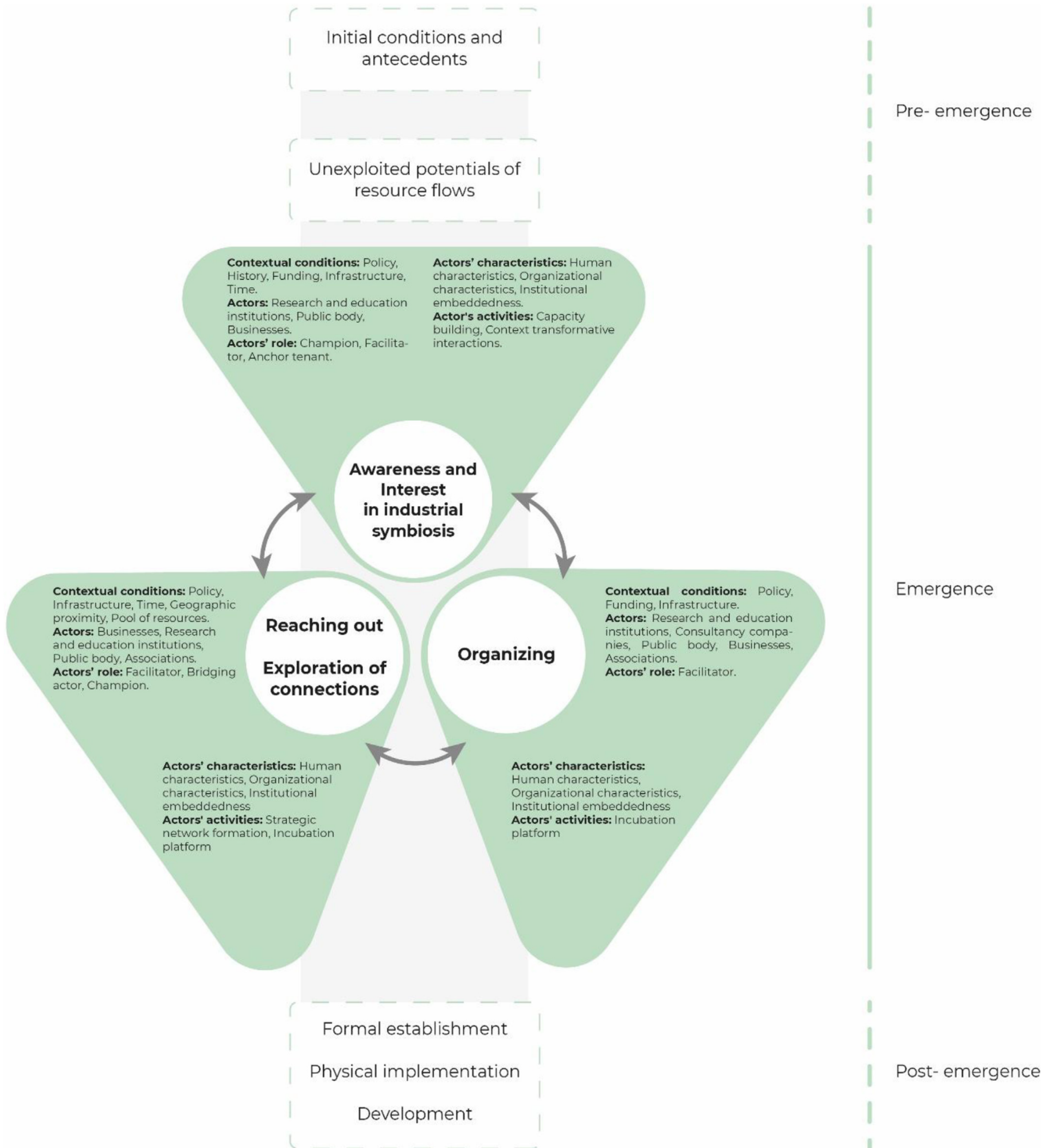

Figure 3.1. IS emergence model. Source: Mortensen & Kørnøv (2019).

3.2.2 Barriers to engagement of SMEs in industrial symbiosis

Although frameworks like the one by Mortensen & Kørnøv (2019) provide a good tool to gain insight into critical factors for the emergence of industrial symbiosis, there is no direct focus on barriers. For the purpose of the current research, an additional framework was constructed to guide the study. This second framework consists of a list of barriers that have surfaced in the literature review of Section 2.2. An overview of these barriers can be found in Table 3.1. The structure of Ormazabal et al. (2018) is followed, dividing barriers into two groups: hard barriers and human barriers.

Some barriers were mentioned in the literature surrounding industrial symbiosis and eco-innovation, but not in the literature relating to district cooling, and vice versa. These differences may be attributed to the fact that industrial symbiosis is a broader area of study. This means that the barriers might apply to only certain aspects of industrial symbiosis, but perhaps not to shared refrigeration. It is therefore necessary to assess whether these barriers apply to the concept of shared refrigeration in Dutch industrial parks.

A definition for each barrier was added for clarification. These definitions were based on the scientific literature and tailored to the purposes of the current research, and are displayed in italics below each barrier in Table 2.2.

Table 3.1. Synthesis of barriers to district cooling implementation and engagement of SMEs in industrial symbiosis and eco-innovation *(continued on next page)*.

Classification	**Barrier**	**Sources**
Hard barriers	Insufficient finances or financial incentives *A lack of financial resources among stakeholders, or a lack of financial incentives for them to engage in shared refrigeration*	Eveloy & Ayou (2019), Rezaie & Rosen (2012), Vasilev & Unzhakov (2020), Ormazabal et al. (2018), Domenech et al. (2020), Corder et al. (2014)
	Insufficient technological knowledge or codification *Insufficient technological knowledge held by stakeholders to engage in shared refrigeration, or insufficient codification of this knowledge*	Eveloy & Ayou (2019), Rezaie & Rosen (2012), Vasilev & Unzhakov (2020), Ormazabal et al. (2018), Patricio et al. (2018), Domenech et al. (2020), Corder et al. (2014), Ha et al. (2021)
	Inadequate provision of information *Inadequate dissemination of information regarding potential opportunities for engagement in shared refrigeration, and/or the related requirements and consequences (including benefits and disadvantages)*	Eveloy & Ayou (2019), Sernhed et al. (2018), Vasilev & Unzhakov (2020), Ormazabal et al. (2018), Patricio et al. (2018), Domenech et al. (2020), Corder et al. (2014), Ha et al. (2021)
	Lack of time to invest in IS engagement *Insufficient availability of time to invest in IS engagement among stakeholders*	Patricio et al. (2018), Domenech et al. (2020), Corder et al. (2014)
	Difficulty finding suitable locations for implementation *Difficulty finding locations where opportunities for shared refrigeration are available, feasible and viable*	Rezaie & Rosen (2012)

Table 3.1. Synthesis of barriers to district cooling implementation and engagement of SMEs in industrial symbiosis and eco-innovation *(continued)*.

Classification	Barrier	Sources
Human barriers	Lack of commitment by firm leaders *A lack of interest and/or commitment by leaders of firms that could form potential partners in shared refrigeration*	Ormazabal et al. (2018), Cervo et al. (2019), Klewitz et al. (2012), Sáez-Martinez et al. (2016)
	Lack of public awareness and interest *A lack of awareness and interest about shared refrigeration among the general public*	Eveloy & Ayou (2019), Palm & Gustafsson (2018), Vasilev & Unzhakov (2020), Ormazabal et al. (2018), Cervo et al. (2019)
	Having a short-term focus *Firms having a short-term focus regarding investments and other business-related activities*	Ormazabal et al. (2018), Domenech et al. (2020), Corder et al. (2014), Holt et al. (2000), Petts et al. (1999)
	Distrust of potential symbiotic partners *A distrust of other stakeholders that could be potential symbiotic partners held by firms and/or their leaders*	Rincón-Moreno et al. (2020), Cervo et al. (2019), Corder et al. (2014)
	Fear of output quality issues *A fear held by stakeholders that engaging in shared refrigeration might jeopardize the output quality of their production*	Rincón-Moreno et al. (2020), Turken & Geda (2020)
	Fear of not being worth the investment *A fear held by stakeholders that engaging in shared refrigeration will not be worth the investment*	Sernhed et al. (2018), Ormazabal et al. (2018), Cervo et al. (2019), Domenech et al. (2020), Corder et al. (2014)
	Lack of cooperation between public and private sector *Insufficient cooperation between public and private bodies with regards to shared refrigeration or similar initiatives*	Eveloy & Ayou (2019), Sernhed et al. (2018), Palm & Gustafsson (2018), Sáez-Martinez et al. (2016), Triguero et al. (2013)

3.2.3 Combined approach

As partly mentioned before, the use of one of the two frameworks described above separately was not deemed sufficient for the purposes of the current research. The model by Mortensen & Kørnøv (2019) was designed to describe critical factors for successful emergence of industrial symbiosis initiatives, taking an approach that focuses on enabling factors rather than on barriers. Conversely, the list of barriers described in Section 3.2.2 takes a barrier-oriented approach rather than focusing on the enabling factors. A combined approach using both frameworks makes for a double-sided, more complete approach that is suitable for the purposes of the current research. The research has therefore been built on both these frameworks.

3.3 Research structure

In Figure 3.2, a schematic overview of the research process is displayed in a research flow diagram. It gives an indication of which steps will be taken to answer the sub-research questions and the main research question.

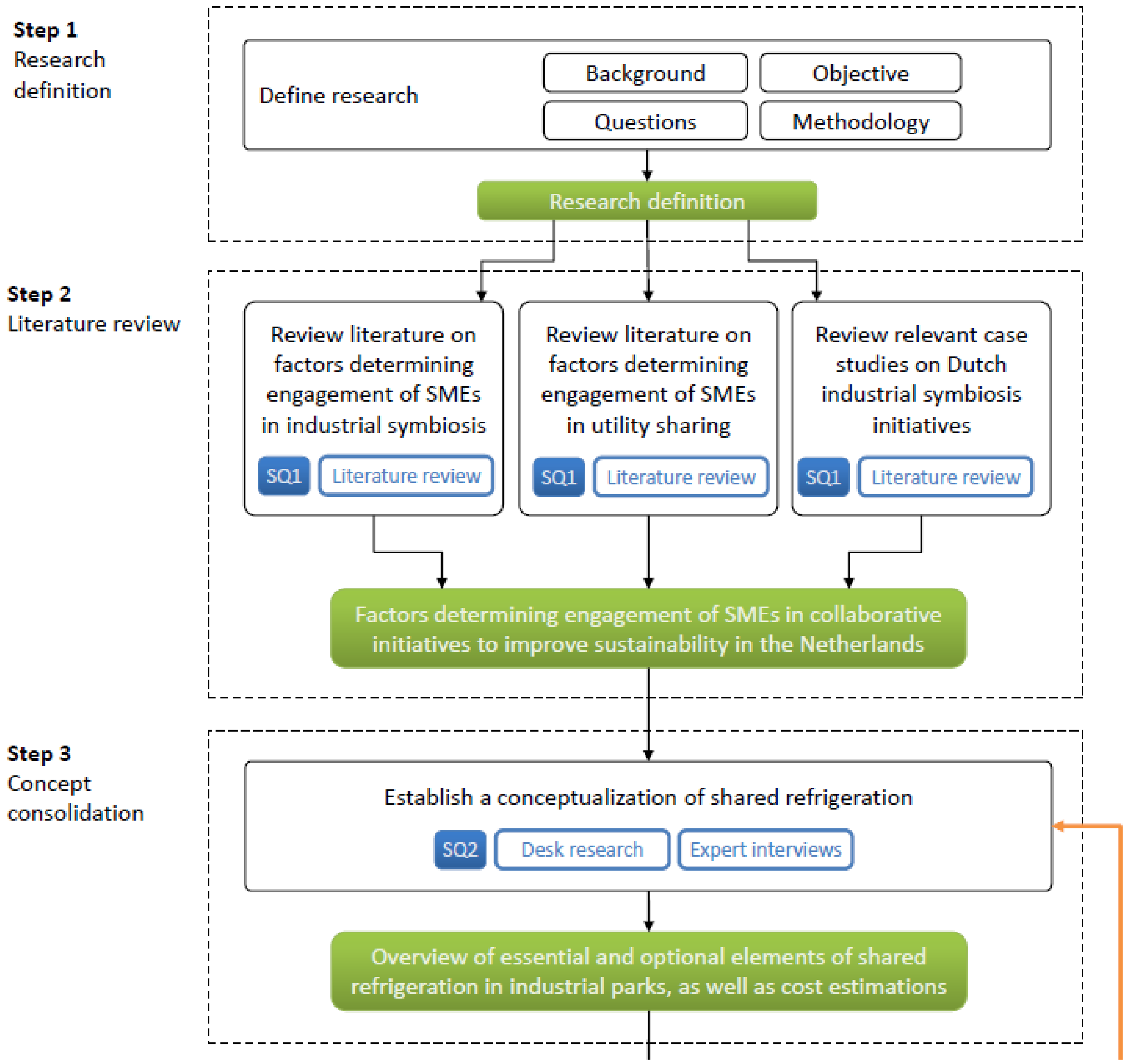

Figure 3.2. Research flow diagram *(continued on next page)*.

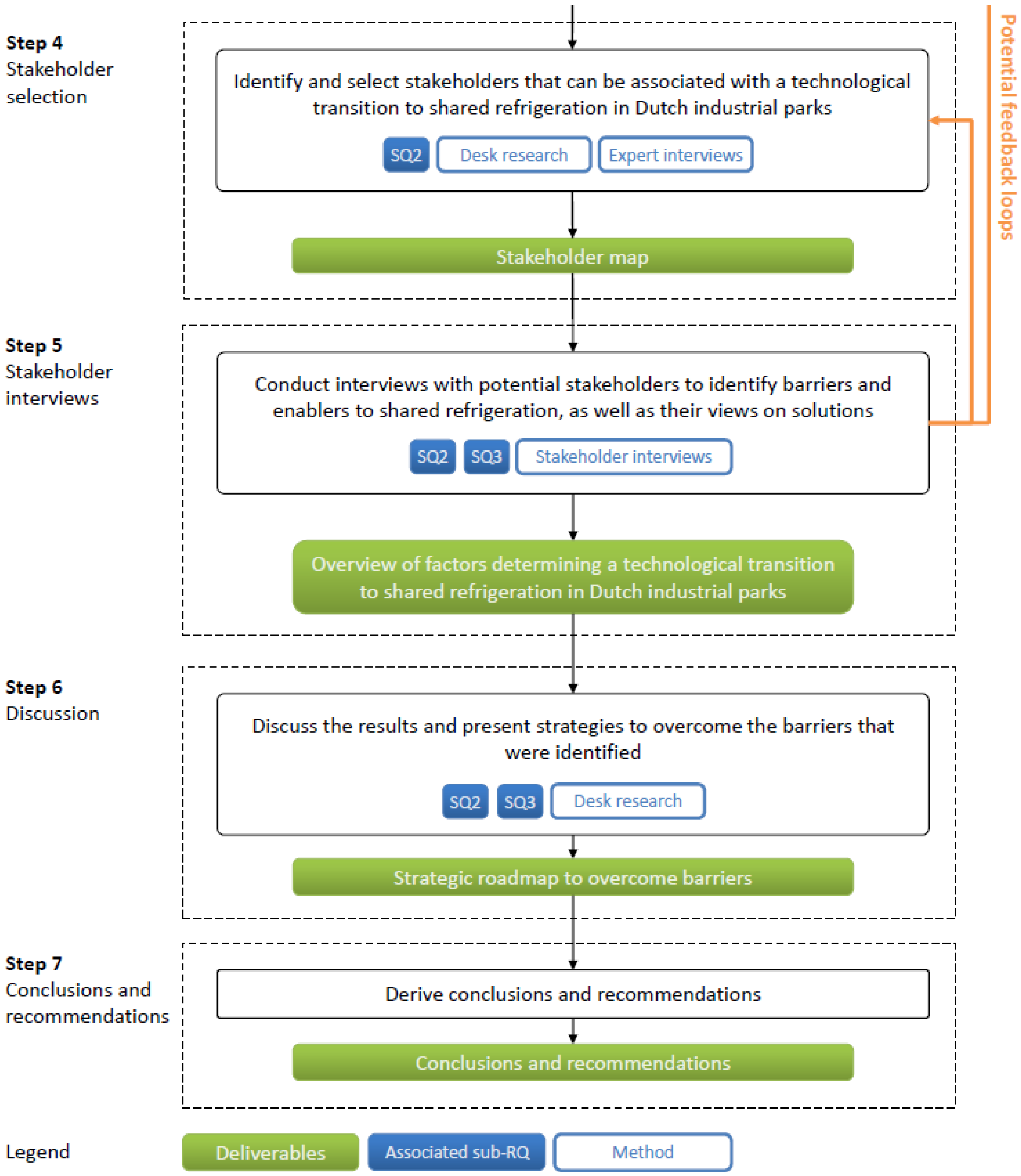

Figure 3.2. Research flow diagram *(continued)*.

3.3.1 Literature review

A literature review was carried out to identify knowledge gaps for shared refrigeration in scientific industrial symbiosis and eco-innovation literature. As shared refrigeration is a relatively unexplored topic, search terms were broadened to include the similar topic of district cooling as well as literature on engagement of SMEs in industrial symbiosis. The literature review has already been described in Chapter 2.

3.3.2 Concept consolidation (preparatory interview round)

To avoid ambiguities in the research, a small number of field experts with expertise in the field of refrigeration were interviewed to identify how a shared refrigeration system would be structured technically.

3.3.2.1 Objective of the preparatory interview round

This interview round had the goal of identifying what elements of a shared refrigeration system would be absolutely necessary and what elements would be optional. This general overview of the structure and functioning of shared refrigeration systems was used to explain the concept to stakeholders that were interviewed in the main interview round of the thesis to identify the barriers and enablers to shared refrigeration. In order to safeguard the quality of those interviews and the findings that resulted from them, it was important to make the potential and the limits of the concept clear to the interviewees. Therefore, based on the results of the first (expert) interview round, a general conceptualisation was made which was sent to the participants of the second (main) interview round to educate them about the concept before asking them for their visions and expectations. In this sense, the first interview round can be regarded as the **preparatory** interview round, while the second interview round was the main interview round.

To come to a more detailed conceptualization, it was important to investigate what the absolutely required elements of a shared refrigeration system would be, and which elements could constitute options. The participants were asked about their views on this, as well as their thoughts on how the system could be managed, and what they think would be the economic and environmental benefits and drawbacks of the new system.

A second objective of this round of interviews was to further gather information about the current and future state of affairs with regard to climate installations with emphasis on trends in sustainability and cooperation. The participants were asked what kind of problems they often see in their operations, and to what extent they think the concept of shared refrigeration can offer a solution to these. The participants were also asked what they think are advantages, challenges and risks of shared refrigeration. This information was valuable for the main interview round, as it allowed for more detailed and knowledge-supported discussions, leading to more qualitative results.

In order to fulfill these objectives, the interviews were divided into six parts that each attempt to shed light on one of these aspects. The structure of the interviews, the different parts and their respective sub-goals will be explained in Section 3.3.2.3.

3.3.2.2 Expert selection

The target group of this interview round consisted of people with relevant positions in the refrigeration installation industry, who have extensive experience in the construction of refrigeration equipment and have a good view of current and future developments in the world of refrigeration technology. Due to their tight interactions with both customers and governments, as well as their technical expertise, they were the ideal target group for this interview round.

The experts to participate in this interview round were selected according to the following criteria. Each participant was required to meet all of the criteria in order to be eligible for participation. The criteria had the goal to establish whether the participant had relevant expertise in a suitable area (technological and/or managerial aspects of industrial refrigeration) and how much work experience the participant had in this field.

1. The participant is involved in an organization that focuses on the construction and/or maintenance of industrial refrigeration systems
2. The participant has expert knowledge about one or more of the following points:
    a. Technical aspects of industrial refrigeration system construction
    b. Managerial aspects of industrial refrigeration system construction
    c. Practical aspects of industrial refrigeration system construction
    d. Technical aspects of industrial refrigeration system maintenance
    e. Managerial aspects of industrial refrigeration system maintenance
    f. Practical aspects of industrial refrigeration system maintenance
3. The participant has at least ten years of relevant work experience in the field of industrial refrigeration

An academic grade or minimum education level was not included in the list of hard requirements, as this would possibly have affected the quality of the responses. This is because having relevant practical experience in industrial refrigeration construction and maintenance is not limited to academically educated people. For the purpose of this interview round, it was important to include participants that have practical experience, as this was likely to lead to useful insights about practical possibilities and limitations for the shared refrigeration concept. This practical knowledge of industrial refrigeration aspects more often than not resides in people with practical education. It was therefore decided that the amount of experience was a leading criterion for the selection of participants, rather than the highest level of education.

3.3.2.3 Interview structure

The explorative expert interviews followed a semi-structured approach to allow for qualitative input from the participants. Semi-structured interviews give the researcher the opportunity to identify a wider range of potential leads, and are useful in cases where the research is examining uncharted territory (Adams, 2015), as is the case for this research.

The interviews followed an approach of “funneling”, starting off with general questions that are more open in nature, after which the topics are narrowed down to get more specific answers. For each question, a set of follow-up questions was devised in order to guarantee the quality of the participants’ responses as much as possible. These follow-up questions were asked where it was deemed necessary.

The interviews were divided into six parts, each serving a different goal. The different parts and their respective labels and goals are described in Table 3.2. The full list of questions used in the first round of interviews can be found in Appendix D.

Table 3.2. Different parts and goals of the first interview round.

Part	**Label**	**Goal**
1	Introduction of participant	To understand the role of the participant in the organization, and the role of the organization in the broader environment. This was useful to assess the quality and representativeness of the participant's responses.
2	Current and future situation of industrial refrigeration	To understand the current and (expected) future trends and developments in the field of industrial refrigeration, with emphasis on problems the participant has encountered during construction and/or maintenance of refrigeration systems.
3	General and technical aspects of shared refrigeration	To understand the participant's view on the possibilities and opportunities of shared refrigeration, as well as the participant's thoughts about potential benefits and drawbacks. Moreover, the participants were asked what they think are required and optional elements of shared refrigeration systems.
4	Organizational structure and realization of shared refrigeration	To understand the participant's view on the potential organizational structure surrounding a shared refrigeration system once it has been constructed, as well as the participant's view on the realization process. For example about who will manage the system, who will maintain it, who will take the lead in the realization phase, and how finances would be organized.
5	Economic and financial aspects of shared refrigeration	To understand the participant's view on the economic and financial opportunities, benefits and drawbacks of shared refrigeration systems.
6	Environmental aspects of shared refrigeration	To understand how the participant thought shared refrigeration systems would positively or negatively impact the environment.

The interviews lasted approximately 45 minutes, and were carried out physically, by phone, or by video call, depending on the circumstances and wishes of the participant. Whereas face-to-face interviews tend to offer more opportunities to identify nonverbal cues (Sekaran & Bougie, 2016), the participants were given the freedom to choose whatever they felt comfortable with because of the potential health risks posed by face-to-face meetings because of the COVID-19 pandemic. All participants were asked to read a consent form stating the terms and conditions of their participation (which can be found in Appendix B) in advance, and to provide written or verbal proof of their agreement to participate.

As the participants were likely to have different levels of English language proficiency, the interviews with all participants were conducted in Dutch, the native language of the participants and the researcher, in order to prevent misconceptions and safeguard the quality of the results. Translations to English for the purposes of the current research were made by the researcher, who is in the possession of a certificate of proficiency in English at C2 level of the Common European Framework of Reference for Languages (CEFR) issued by the University of Cambridge.

3.3.2.4 Post-interview analysis

After the interviews of the preparatory round were conducted, all interview recordings were transcribed by hand as machine translations for Dutch language voice recordings were deemed of poor quality, and analyzed using a data reduction process based on a combination of a predefined set of codes and on-the-fly coding. The coding and analysis process was done using the Atlas TI software. A more detailed description of the coding process and the full code list for the first round of interviews can be found in Appendix F. The results were then anonymized, accumulated and synthesized according to the terms and conditions. The findings were used to come to a definitive conceptualization of a shared refrigeration system that would be presented to the participants of the main interview round for the reasons described in Section 3.3.2.1.

3.3.3 Stakeholder interviews (main interview round)

The main data collection of this research project consisted of a number of interviews with relevant participants from stakeholder groups that would be likely to be involved in a potential shared refrigeration initiative. The interview round was structured in a way that aligns to the frameworks guiding this research as presented in Section 3.2, as will be described in the following subsections.

3.3.3.1 Objective of the main interview round

This second (main) round of interviews had several sub-goals that together had the common goal of shedding light on the factors that determine the implementation of shared refrigeration in Dutch industrial parks. The first goal of the interview was to **identify the actor characteristics** of the participant and the organization in which the participant is involved (for example: does the organization have a culture that is open to innovation, collaboration and sustainability), what **actor role** would the participant see for the organization in the light of shared refrigeration, and what **actor activities** would his or her organization undertake. These insights were important to identify if the organization is currently in line with the characteristics of an organization that fosters the chance of success of the emergence process, as described by Mortensen and Kørnøv (2019), or if there is still work to be done to make culture changes. In addition, the participants were asked to express their views on what the **characteristics, roles and activities of other actors** in a process of implementation of shared refrigeration would be. By cross-comparing their views and comparing them with the dynamics described by Mortensen and Kørnøv (2019), light can be shed on potential misalignments or opportunities arising from the expectations of different stakeholder groups. Furthermore, the interviews aimed to explore the **contextual factors** that may determine the emergence process of shared refrigeration. The goal of the questions dedicated to this exploration was to assess for each contextual condition mentioned by Mortensen and Kørnøv (2019) to what its state is in the Dutch context, and how the participant thinks these factors will (need to) develop in the future.

The framework by Mortensen and Kørnøv (2019) distinguishes three iterative phases of the industrial symbiosis emergence process (awareness and interest creation, reaching out and exploration of connections, and organizing). The questions in this section may be followed upon by additional sub-questions during the interview to shed more light on the diversity with respect to these different phases, if that is deemed necessary.

In accordance with the second framework guiding this research, the interviews aimed to explore **barriers** currently in place for shared refrigeration technology, by assessing for each barrier from the list described in Section 3.2.2 whether the participant thought it is present in the Dutch context, and to identify any additional barriers the participant might think are present.

Finally, the interviews offered the participants the opportunity to elaborate on what they see as potential solutions to the barriers that are currently in place for shared refrigeration. The semi-structured nature of the interviews allowed for a broad input by the participants, and the identification of a broad range of leads.

3.3.3.2 Stakeholder selection

The stakeholder selection process was determined according to the framework of Mortensen & Kørnøv (2019), which provides insight into which actors are relevant for industrial symbiosis emergence processes, as well as the results of the preparatory interview round, in which the participants were asked which stakeholders they thought would be involved. The extension of the framework with these results from the expert interviews made for a more solid approach, as extra care was taken not to overlook any stakeholder groups.

For each stakeholder group, knowledgeable representatives were identified and contacted. All (potential) participants were found using Google, LinkedIn, corporate websites, news articles, and via recommendations by earlier participants. All contacts were approached through email or by telephone. An email was sent to all potential participants explaining the theme and purpose of the study, together with a short presentation of the research project and the shared refrigeration conceptualization that was established after the preparatory interview round. The presentation was sent to the participants in .pdf format to make sure the participants would understand the shared refrigeration system and the purpose of the interview. If the participants replied and agreed to participate, they were sent the interview questions, as well as a consent form to explain the terms and conditions of their participation in the research. They were asked to read the form and either sign it, or provide their verbal consent in the audio recording that was to be made during the interview. The consent form can be found in Appendix B.

3.3.3.3 Interview structure

The explorative expert interviews followed a semi-structured approach to allow for qualitative input from the participants. Semi-structured interviews give the researcher the opportunity to identify a wider range of potential leads, and are useful in cases where the research is examining uncharted territory (Adams, 2015), as is the case for this research.

The interviews followed an approach of “funneling”, starting off with general questions that are more open in nature, after which the topics are narrowed down to get more specific answers. For each question, a set of follow-up questions was devised in order to guarantee the quality of the participants’ responses as much as possible. These follow-up questions were asked where it was deemed necessary.

The interview was divided into six parts, each serving a different goal. The different parts and their respective labels and goals are described in Table 3.3. The full list of questions used in the second round of interviews can be found in Appendix E.

Table 3.3. Different parts and goals of the second interview round.

Part	**Label**	**Goal**
1	Introduction of participant and actor characteristics	To understand the role of the participant in the organization, and the role of the organization in the broader environment. This was useful to assess the characteristics of the organization.
2	Open question about thoughts about shared refrigeration	To give participants the opportunity to mention barriers, enables, threats and opportunities they might see for the concept of shared refrigeration. The position at the beginning of the interview served to avoid biasing as much as possible.
3	Actor roles and activities	To understand the participant's view on what role he or she envisioned for his or her own organization, as well as for other actor groups, would they participate in the development of a shared refrigeration initiative.
4	Contextual conditions	To understand the participant's view on the contextual conditions that are critical for the emergence of IS initiatives according to Mortensen & Kørnøv (2019).
5	Barriers	To understand which barriers the participant thought are present for shared refrigeration. The participants were presented the list of barriers assembled in Section 2.3, and asked to give their view on each of them. They were also asked if they saw any additional barriers.
6	Conclusion	To give participants the opportunity to add information to the interview, and to suggest other participants for further interviewing.

The interviews lasted approximately 45 minutes, and were carried out physically, by phone, or by video call, depending on the circumstances and wishes of the participant. Whereas face-to-face interviews tend to offer more opportunities to identify nonverbal cues (Sekaran & Bougie, 2016), the participants were given the freedom to choose whatever they felt comfortable with because of the potential health risks posed by face-to-face meetings because of the COVID-19 pandemic. All participants were asked to read a consent form stating the terms and conditions of their participation (which can be found in Appendix B) in advance, and to provide written or verbal proof of their agreement to participate.

As the participants were likely to have different levels of English language proficiency, the interviews with all participants were conducted in Dutch, the native language of the participants and the researcher, in order to prevent misconceptions and safeguard the quality of the results. Translations to English for the purposes of the current research were made by the researcher, who is in the possession of a certificate of proficiency in English at C2 level of the Common European Framework of Reference for Languages (CEFR) issued by the University of Cambridge.

3.3.3.4 Post-interview analysis

After the interviews of the preparatory round were conducted, all interview recordings were transcribed by hand as machine translations for Dutch language voice recordings were deemed of poor quality, and analyzed using a data reduction process based on a combination of a predefined set of codes. The coding and analysis process was done using the Atlas TI software. A more detailed description of the coding process and the full code list for the first round of interviews can be found in Appendix G. The results were then anonymized, accumulated and synthesized according to the terms and conditions. The results were assimilated according to a structure based on the framework by Mortensen & Kørnøv (2019) and the list of barriers that together form the theoretical framework of the current research.

3.3.4 Post-results

A discussion of the results of the main interview round was made, serving to assess the barriers and opportunities for shared refrigeration in Dutch industrial parks identified by the participants. The results were discussed in the light of the framework for success of industrial symbiosis proposed by Mortensen & Kørnøv (2019), to assess to what extent the current state of the Dutch context is in line with established success factors for industrial symbiosis emergence. Moreover, the barriers mentioned by the participants were compared to the barriers to engagement of SMEs in industrial symbiosis, in order to assess for each barrier whether it is likely to be present and/or relevant in the Dutch context or not. Where necessary, additional sources were consulted to verify statements made by the participants. Following the analytic discussion of the results, the research went on to provide recommendations to the stakeholders to facilitate the removal of the barriers to shared refrigeration implementation in industrial parks, based on scientific literature from the fields of industrial symbiosis, eco-innovations, policy mixes, adoption and diffusion, sustainable transitions and design dominance.

The research was concluded by answering the main research question, after which the limitations of the research were pointed out and recommendations were made for future research and development.

4 Concept consolidation

This chapter aims to investigate what elements a shared refrigeration system would consist of. It explores what elements are an absolute necessity and what elements could be optional. Moreover, it attempts to sketch a rough picture of how a shared refrigeration system would be organized and maintained, as well as an estimation of the costs associated with it. As no literature on the new technology is present, interviews with field experts were the primary source of information.

4.1 Selection of participants

The first interview round served mainly as a preparation trajectory for the second round of interviews, which forms the main part of the thesis. Therefore, three participants were deemed to be sufficient to gather the desired information for the purposes of the first interview round. The criteria by which the participants were selected were described in Section 3.3.2.2.

In Table 4.1, an overview of the participants of the first interview round is provided, including their function and a short description of their characteristics. All participants satisfy the selection criteria and are therefore considered to be trustable experts whose opinion is representative and valuable for the purposes of this research.

Table 4.1. Description of participants for the first interview round.

Participant	**Function**	**Description**
1A	**Founder/Chief Executive Officer (CEO)** at a Dutch company specialized in construction and maintenance of industrial refrigeration equipment	This participant has over 30 years of experience in the field of industrial refrigeration, and has expert knowledge about technical, managerial, and practical aspects of both construction and maintenance. As a CEO, the participant has good knowledge of the market, legislation and recent trends and developments.
1B	**Co-owner/Chief Technical Officer (CTO)** at a Dutch company specialized in construction and maintenance of industrial refrigeration equipment	This participant has over 20 years of experience in the field of industrial refrigeration, and has expert knowledge about technical, managerial, and practical aspects of both construction and maintenance. The participant started out as a refrigeration mechanic, and can therefore be considered an expert in the practical field as well.
1C	**Service manager** at a Dutch company specialized in construction and maintenance of industrial refrigeration equipment	This participant has over 12 years of experience in the field of industrial refrigeration, and has expert knowledge about technical, managerial, and practical aspects of the maintenance of industrial refrigeration equipment.

4.2 Results

The following section will summarize the responses of the participants in an aggregated and anonymized manner. The interviews with the three participants were carried out in Dutch, the native language of the participants and the researcher, in order to safeguard the quality of the results. Therefore, any quotes or paraphrases that are included in the following sections are translations of the original transcripts.

4.2.1 Current situation, problems and trends

4.2.1.1 Customers

Customers are typically budget-oriented and are not seldom overwhelmed by the price level. They therefore often try to reduce costs by opting for cheaper equipment and/or cutting in the maintenance rate. Such choices affect the equipment quality negatively. Overall, customers tend to have a short-term focus and have limited knowledge about refrigeration technology. Although they are indeed often open to suggestions and positive towards making their business more sustainable, they do not tend to opt for the more expensive, environmentally friendlier installations if those do not also offer financial advantages. Investment costs often seem to be the decisive factor.

Customers (i) for whom refrigeration is a crucial part of their business, (ii) who have larger installations, or (iii) who are themselves the business owner, tend to be more alert for defects, more cooperative and have more knowledge of refrigeration equipment. However, customers (i) for whom refrigeration is a “necessary evil” that does not directly increase the value of their products, (ii) who have smaller installations, or (iii) are not themselves the business owner, tend to underestimate the value of maintenance and tend to be less knowledgeable about refrigeration technology in general.

According to the participants, there seems to be a general underestimation of the value of maintenance among customers. All participants indicate that poorly maintained installations are common. Leakage of harmful refrigerants is also commonly encountered by maintenance personnel.

4.2.1.2 Government

The national government is seen by the participants as an influential and powerful actor that can steer the industry in “the right direction” by means of policy instruments such as laws, regulations and subsidies (which are increasingly being applied). The participants indicate that installation companies such as theirs tend to be problem-solving and ambitious in terms of sustainability. They usually attempt to sell more environmentally friendly installations to customers, and advise them to opt for natural refrigerants. However, as the customers often desire lower prices, installation companies are somewhat forced to sell cheaper installations employing synthetic refrigerants. One participant explained that if they would not offer the cheaper installations anymore, customers would simply buy the equipment from competitors who do still offer them (one participant points out that there are installation companies active in the market who deliver cheap, low-quality products). The participants are generally positive towards the stricter regulations regarding sustainability imposed by the government (although one participant mentioned that rapidly changing regulations are a challenge to keep up with), and they indicate that government policy is crucial in upholding the quality of refrigeration equipment. Moreover, one participant indicates that the changing regulations imply guaranteed work and income for installation companies.

4.2.1.3 Development trends

Despite the aforementioned difficulties, the participants see a trend of customers switching increasingly to natural refrigerants. They associate this with the gradual phasing-out of synthetic refrigerants which is set to be completed in 2030[5], leading to scarcity and higher prices of these refrigerants. The participants explain that natural refrigerants are already the norm for very small (due to regulations) and large refrigeration installations (due to scale effects and longer investment horizon). For small- to medium-sized installations, natural refrigerants are still financially unattractive, resulting in the fact that there are still many installations that run on unsustainable refrigerants. However, the participants state that this "gap" is slowly closing. Another trend seen by the participants is that customers are interested in heat regeneration, and that this is increasingly being applied. The participants further indicate that new synthetic refrigerants are still being developed, and that these are increasingly sustainable. However, the 2030 deadline for phasing out has thus far not been adapted because of this trend.

The participants indicate that technical development is happening, but that it is generally limited to the component level and in the field of refrigerants. System-level developments are much more scarce. One participant indicated that the refrigeration industry is a "remarkably slow-changing one", and that about 60% of the technology is the same as it was thirty years ago. The participant indicates that about 95% of existing refrigeration equipment is based on the vapor-compression principle, and that other principles such as sorption refrigeration are uncommon.

4.2.1.4 Personnel shortages

The participants indicate that there is a shortage of construction and maintenance personnel, one participant even indicating that this will be a critical problem in the future. They also note that construction and maintenance personnel tend to have insufficient knowledge about new, more sustainable technologies, sometimes resulting in errors during installation or maintenance. One participant indicates that service-friendliness is insufficiently being taken into account while designing and constructing new equipment, leading to inadequate performance and difficulties during maintenance. The participant attributes this to the aforementioned knowledge insufficiency and shortage of personnel.

4.2.1.5 Utility sharing and industrial symbiosis

All participants agree that utility sharing and industrial symbiosis in the realm of industrial refrigeration are possible. Two of them indicate that they see it as "the future". One participant indicates that potential partners will be easily interested in participating in utility sharing and industrial symbiosis initiatives if it leads to lower investment costs, whereas the other participants are somewhat more cautious in their statements. They emphasize that it will be challenging to realize utility sharing and industrial symbiosis initiatives. One participant adds that there is a shortage of suitable industrial areas for such initiatives.

[5] From 2030, newly produced synthetic refrigerants will be banned. The use of some refrigerants in a regenerated form will still be allowed. However, this policy will likely lead to scarcity and higher price levels, making it increasingly expensive to operate installations with synthetic refrigerants.

4.2.2 Advantages of shared refrigeration

4.2.2.1 Environment

All participants agree that shared refrigeration will have environmental advantages over the current, fragmented situation regarding refrigeration equipment. The participants indicate that waste heat recycling - for example the pairing to a district heating network - will be much easier to realize if the refrigeration equipment is centralized. Two participants indicate that the large scale will allow for a more efficient connection to the power grid, and one participant notes that noise pollution (which is now a common phenomenon caused by refrigeration equipment) can be more easily reduced by locating the system strategically and investing in noise reduction.

One participant strongly believes that large energetic savings can be achieved thanks to the shared system, as a result of the use of the so-called “simultaneity factor” (a term which is in this case synonym to the term “coincidence factor”). This factor relates to the fact that in practice, the situation where all refrigeration appliances are turned on at the same time virtually never occurs. Therefore, the situation where refrigeration equipment is centralized will require a lower capacity than would have been necessary if every company would have its own refrigeration equipment, resulting in both financial and energetic advantages.

4.2.2.2 Equipment lifespan

The large scale and centralized nature of a shared refrigeration system will result in the use of high-quality components, which are more reliable and have a longer lifetime (one participant estimates the total lifetime of such a system will be increased by 10 years, from 15 to 25) and can be revised in case of defects instead of having to be disposed and replaced. Moreover, the participants indicate that as centralization offers opportunities for better monitoring, defects might be spotted earlier and maintenance will be more efficient. During construction, the large scale will likely result in procurement advantages.

4.2.2.3 Enforcement of laws and regulations

One participant notes that due to the centralized nature of a shared refrigeration system, enforcement of laws and regulations will become easier. This will make defects and fraud less likely, resulting in benefits for both the environment and the government. Moreover, two participants agree that shared refrigeration will be an opportunity for the government to accelerate the shift to natural refrigerations.

4.2.2.4 Investment size

As the initiative will likely be funded by a group of investors and/or government subsidies, all participants agree that the initial investment costs for individual partners will likely decrease. One participant adds that the system requires less space in the buildings of individual partners, which also has cost advantages for the customers.

4.2.3 Barriers and challenges to shared refrigeration

4.2.3.1 Agreements and responsibilities

All participants agree that losing control over the equipment will be a point of concern for potential partners. Two participants note that agreements and contracts must carefully be created, and responsibilities should clearly be defined.

4.2.3.2 Investor attractions

All participants note that a shared refrigeration system will require a large initial investment due to its scale. This investment is likely to be brought up by investors, who will need to be attracted and convinced of the potential of the system. This process is further complicated because of the complexity of the necessary cost-benefit analysis. The participants indicate that it will be very difficult to estimate the costs of a shared refrigeration due to its variability in capacity (depending on many factors such as the number of consumers, the distance between them, their demands, etc.). As a result, calculating the profitability will be a challenge, most importantly leaving the question open as to whether or not the system will be financially interesting at all for both investors and consumers. Care should be taken to create a sound map of all costs and benefits associated with shared refrigeration.

4.2.3.3 Collaboration and competition

One participant indicates that a challenge might arise in the collaboration between installation companies. As a shared refrigeration system will imply that either one installation company will take care of the equipment for all companies (leading to a “winner-takes-all” situation), or several installation companies will have to work together, which will pose challenges due to reliance on trust and a potential misalignment of business models. The competitive risks that arise from these scenarios might lead to the situation where installation companies are reluctant to support shared refrigeration initiatives.

4.2.3.4 Design challenges

Two participants stress that designing such a large system with its extensive infrastructure will be a challenge. Many factors will have to be taken into account. One participant gives the example of one company suddenly drawing large amounts of cold energy from the grid, resulting in other companies losing a bit of their refrigeration capacity because the system will need some time to accommodate. This will challenge the delivery promise towards the customers. The participants also agree on the effect that long pipelines will have on the system’s efficiency - longer pipelines mean more losses to friction, so that care must be taken to design the system in such a way that these losses will be reduced to a minimum.

Furthermore, as the system consists of two temperatures, consumers are more or less bound to these. Consumers who desire higher temperatures can employ additional components to raise the temperature of the refrigerant, but this will go at the cost of some power capacity. Lower temperatures cannot be achieved with simple equipment, implying that if customers require lower temperatures, they still have to invest in individual refrigeration equipment that can reach those temperatures.

A system with large amounts of refrigerant calls for extensive safety measures. In addition, as failure of the network might result in a large number of companies losing refrigeration power (with large economic consequences and potential claims), care should be taken in designing the network in such a way that the damage can be contained as much as possible.

In terms of waste heat reusal, two participants note that the cold demand from the industry side will probably not be aligned with the heat demand from for example a district heating network, as heat is more often desired during the evenings while many companies will require less refrigeration capacity. This evokes the need for heat-cold storage to be able to compensate for the supply-demand inequality.

One participant notes that solving these design challenges will inevitably lead to higher costs of the system's design and construction.

4.2.3.5 Personnel shortages

One participant argues that the already problematic shortage of adequately trained construction and maintenance personnel might also hinder the development of a shared refrigeration system.

4.2.3.6 Alternative options

One participant notes that the government could also employ other methods to foster a transition to natural refrigerants, such as making their use mandatory by law. This would be a much simpler, easier and less risky way of achieving their environmental goals. However, it would not lead to the same environmental gains as a shared refrigeration system would, because the scale benefits and heat recycling opportunities would be absent.

4.2.4 Financial and organizational aspects of shared refrigeration

4.2.4.1 Initiation

Two participants indicate that the concept will only be feasible in newly developed industrial areas. They indicate that governments should take the leading role in selecting suitable locations for implementation of shared refrigeration projects. In selecting suitable locations, care should be taken to assess possibilities for waste heat recycling, like the vicinity of newly built suburbs which can be equipped with district heating. One participant stresses the benefits of combined heat and cold generation, stating that it will lead to importantly higher financial returns. Governments are also in the position to make legislation, and could make attachment to the refrigeration grid mandatory for companies who wish to settle themselves in the industrial area where shared refrigeration is being developed. Furthermore, government subsidies might play an important role in launching the development of the projects.

One participant indicates that large energy companies might be suitable partners to take a leading role in the development, as they typically have extensive experience in the energy environment and a large resource pool. However, another participant contradicts this, stating that leaving the control to a large company will lead to distrust among participants. The participant argues that a bottom-up or middle-out process, led by for example a consortium of local businesses, is more suitable as the partners will be more willing to cooperate.

4.2.4.2 Agreements and contracts

The participants indicate that it is of great importance to communicate the terms and conditions of a shared refrigeration system from an early stage of the development process. Responsibilities must be clearly defined. At an early stage, the developers should discuss with the partners to map their demands in terms of refrigeration capacity, to be able to complete a cost-benefit analysis and calculate the price per kW that consumers will pay for the amount of cold energy they will use. Care should be taken to include a simultaneity factor (as explained in Section 4.2.2) in the calculations. One participant argues that if costs and benefits cannot be entirely clarified, the developers might compensate for potential financial issues by employing a well-designed deposit-and-refund system.

One participant notes that a shared refrigeration system will likely reach to the "front door" of the customers, and that the customers themselves have to take care of installing indoor equipment like evaporators. These can then be connected to the shared refrigeration grid. Although this will entail that customers will still have to invest in their own equipment, the participant notes that this investment will be significantly smaller for the customer than if a complete installation would have to be built.

4.2.4.3 Design and construction

One participant notes that future extensions should be taken into account while designing and constructing the shared refrigeration network. The participant argues that, if the infrastructure is laid out in a way in which it can be extended later on, increasing the refrigeration capacity at the plant level is not a major issue. The infrastructure is thus the limiting factor here.

Another participant notes that the central refrigeration plant should be located strategically to prevent noise pollution as much as possible.

4.2.4.4 Maintenance

The participants indicate that it is likely that a maintenance team will be created, with the task of monitoring and maintaining the equipment either frequently or continuously.

4.2.5 Elements of shared refrigeration

4.2.5.1 Necessary elements

All participants indicate that a shared refrigeration system will be based on a natural refrigerant. They also agree that the entire system, including the cold generator and the infrastructure, should be built *in duplo*, allowing for generation and distribution of two different refrigeration temperatures - one for cooling and one for freezing. The participants indicate that, due to losses in the distribution network, the temperatures that should be produced at the central facility should be -15 °C and -35 °C in order to be able to deliver the standard temperatures of -10 °C and -30 °C to consumers. The participants indicate that an industrial shared refrigeration system must include at least the following **necessary elements**:

1. A central plant with two cold generators
    a. Separator vessels
    b. Compressor sets
    c. Switchgear
    d. Condensers (for ammonia) or gas coolers (for CO_2)
    e. Pumps
2. Infrastructure
    a. Piping (two-way)
    b. Pumps
    c. Equipment to measure the cold use of consumers
        i. Flow meters
        ii. Temperature meters
3. Safety elements
    a. Leak detection equipment (mandatory by law for CO_2 and ammonia, desirable for other installations)
    b. Easily reachable safety/maintenance valves that allow for shortcutting the circuit in case of leakage further on the line
    c. Communication cables for safety systems

4.2.5.2 Optional elements

The participants add that the following **optional elements** might be included in a shared refrigeration system:

4. Heat recycling equipment
    a. Heat exchanger
    b. Heat storage equipment
5. Intermediate pumping stations
6. Switching stations that can serve as I/O modules
7. A hot gas defrosting system[6]
    a. Piping for hot gas distribution
8. Redundant infrastructure to reduce potential downtime
9. A third, lower-temperature network for shock freezing
10. Solar panels to (partially) power the equipment

All participants indicate it is important to account for the losses in the network due to friction. Two participants note that losses due to conduction and radiation can and should be minimized by applying high quality isolation.

[6] This is an energy-saving technology that removes ice formed on evaporators by means of a gas that is heated using the machine's own waste heat, rather than by means of traditional electrical elements. It is already increasingly being applied in current installations. One participant states it will certainly provide added value to a shared refrigeration system.

4.2.6 Two variants

Although the participants generally had aligned visions, they did not all agree on one point, which is the question whether the primary refrigerant itself should be pumped through the distribution piping network, or if the distribution network should be a closed-loop system where a secondary refrigerant acts as an intermediate cold carrier. For the purposes of this thesis, these two variants will be referred to as the *single-loop variant* and the *double-loop variant*, respectively. A schematic layout of the two variants can be found in Figure 4.1. The blue factory on top represents the central refrigeration plant, while the green factory on top represents the consumers, who have been represented by one symbol here for simplicity purposes.

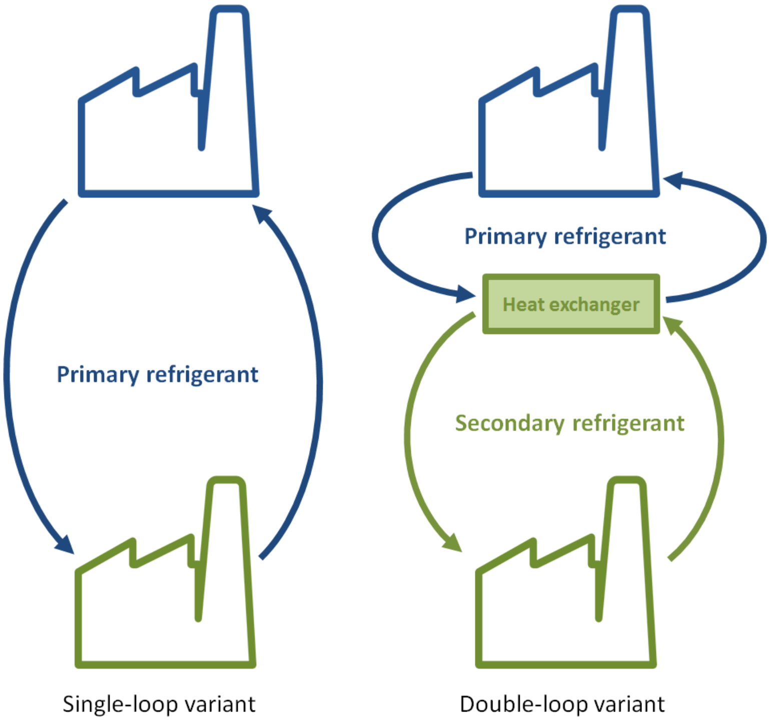

Figure 4.1. Two possible variants proposed by the participants.

For both variants, separate conditions apply, which are explained below.

4.2.6.1 Single-loop variant

In this variant, the primary refrigerant must be CO_2. The participant arguing for this variant notes that ammonia is poisonous when leaked, and as a shared refrigeration system of this variant would contain vast amounts of refrigerant, it will be highly unlikely that any government would allow the use of ammonia as a refrigerant. CO_2 poses less safety risks and would be a plausible option.

The piping infrastructure would be built out of isolated thick-walled stainless steel pipes with expansion arches at regular intervals to prevent breakage due to temperature-induced expansion. The piping has to be laid sufficiently deep below the street level to prevent breakage due to vibrations caused by heavy vehicles like trucks. The refrigeration principle of choice would be a CO_2-pump system, the participant argues, as this is the most flexible option which would satisfy the needs of most consumers.

4.2.6.2 Double-loop variant

In this variant, the primary refrigerant would be either CO_2 or ammonia, as permits will not be a large issue due to the limited amounts of refrigerant in the system compared to the single-loop variant. This has the advantage that ammonia equipment, which requires lower operating pressures and is therefore less costly, can be used instead of more costly CO_2 equipment.

The participant proposes Thermera® or Greenway® Neo N (Participant 1A, personal communication, 13 September 2021) as a secondary refrigerant, as these are non-toxic, eco-friendly and have better viscosity properties at low temperatures than glycol, which has been traditionally applied more.

4.2.6.3 Need for selection

Because these two variants significantly differ on crucial points, they could not both be taken into account for the purposes of the current research. This is because taking both variants into account would likely have led to the situation where the results of the second (main) interview round are not applicable to one or the other variant, which would have put the quality of the findings at risk. A double research, where participants would be asked to express their views on both variants was not feasible timewise. Therefore, it was necessary to make a selection and base the current research on **only one** of these variants. Section 4.5 will discuss this selection and summarize the concept that was eventually presented to the participants of the main interview round.

4.2.7 Actors and stakeholders involved

The participants state that in a shared refrigeration initiative, actors and stakeholders will be involved from the following groups:

- National government
- Municipal government
- Land owner of the industrial site
- Business associations
- Potential customers
- Installation companies
- Component suppliers
- Energy companies

In Chapter 5, a more extensive analysis of potential actors and stakeholders involved in the shared refrigeration development process is described.

4.2.8 The participants' opinion

The participants all agree that shared refrigeration would be possible to realize. Two of them explicitly state it is a viable concept, which has advantages over the current situation. However, the participants note that it will be challenging and difficult to realize due to the complicated technological nature and the many stakeholders that have to be involved. One participant explicitly stated that all technical challenges that could arise can be resolved. This participant expresses the belief that customers will be highly interested in the concept, stating that he finds it strange that such a concept has never been implemented. Overall, the attitude of the participants can be described as positive, although cautious for the many challenges that could occur.

4.3 Final consolidation

The results of the first interview round could be used to create a conceptual definition of a shared refrigeration system in terms of its structure and essential elements, as well as its optional elements. This conceptualization served as a base for the second, main round of interviews. This section comprises the selection between the two variants as described in the previous section, and a consolidation of the concept.

4.3.1 Variant selection

In order to make an educated selection between the two different variants, the two participants that had opposing views (the third participant did not express a preference) were contacted again, and asked to discuss their opinions with each other (the participants are active within the same company) and list the advantages and disadvantages of both variants. Again, they did not come to an agreement as to which variant would be better than the other. However, they managed to provide a list of advantages and disadvantages of both variants. These are summarized in Tables 4.2 and 4.3.

Both variants appear to have about the same number of advantages and disadvantages. However, it can be argued that, as the single-loop variant poses serious health and safety hazards and requires significantly higher investments in infrastructure, as well as frequent safety checks and an extensive safety system, it is somewhat less likely to find support among stakeholders than the double-loop variant. The double-loop variant relies on technologies that are safer, simpler, more flexible, and more well-explored. Although it has energetic disadvantages, these might be compensated for by a paired waste heat recovery appliance and efficient design of piping and other components.

Moreover, as damage to the piping in single-loop variant systems will have larger consequences than damage to the piping in double-loop variant systems, the single-loop variant would be less suited in other areas of the world - for example those where natural disasters like earthquakes, floods and hurricanes are more prevalent, areas that are prone to terrorist attacks, and areas where there is a lower insurance rate and/or a strong claim culture. The single-loop variant will therefore be less suited for worldwide application given the current state of the technology.

For these reasons, the current research has focused on the **double-loop variant**. Future research into the single-loop variant will be included in the recommendations, but it was kept out of the scope of the current research.

Table 4.2. Advantages and disadvantages of the single-loop variant.

Single-loop variant	
Advantages	- Better COP (higher energy-efficiency) - Consumer-side equipment can be smaller in size - Thinner piping for distribution - Lower temperatures can be achieved (although this will in practice not be a critical point)
Disadvantages	- Extra maintenance needed - More mandatory checks and detection equipment - Higher health hazards in case of leakage, ammonia is not a viable option so the system will be limited to CO_2, which implies working with higher pressures - Piping under street level must allow for regular checks, which implies building a maintenance tunnel - Measuring consumption per consumer is more difficult

Table 4.3. Advantages and disadvantages of the double-loop variant.

Double-loop variant	
Advantages	- No hazardous refrigerant outside the refrigeration plant, so no environmental or health hazard in case of leakage - No regular safety checks required due to lower risk - Leak detection can be organized in a cheaper and easier way, through flow meters at regular intervals - There is a lower COP (lower energy-efficiency), but this leads to more heat production which could be beneficial for any heat applications paired to the system - Piping under street level is relatively simple
Disadvantages	- Lower COP (lower energy-efficiency), so a larger installation is required to achieve the same refrigeration power - Consumer-side equipment must be larger in size - Larger piping necessary for distribution

4.3.2 Final conceptualization

The concept that was presented to the participants of the main interview round has a double-loop structure. It consists of the following elements:

1. A central refrigeration plant where cold is generated at two temperatures (-15 °C and -35 °C) using a CO_2 or ammonia vapor-compression installation, which consists of two large separators, compressor sets, pumps, condensers, and switchgear. The cold energy is continuously being transferred from the primary refrigerant in the refrigeration loop to the secondary refrigerant in the distribution loop through a heat exchanger.

2. A two-way, well-isolated piping network located below street level that allows for the secondary refrigerant to be distributed at two temperatures to the network of consumers and then back to the refrigeration plant. Along the pipe lines at regular intervals will be flow meters that serve as leak detectors, as well as valves that are able to shortcut the circuit in case of maintenance or piping failure at a further point. If and where necessary, pumps are installed to support the refrigerant flow.
3. Flow meters and temperature meters at the points where the piping enters the buildings of consumers, to be able to measure their consumption. Valves are also added at these points for maintenance and safety purposes. Consumers can attach internal refrigeration components (for which they take care themselves) to the network.

The following elements can be added optionally:

4. A heat exchanger moving excess heat to a storage module, from which heat can be extracted to serve appliances such as district heating.
5. Switching stations that can serve as I/O modules. These might be convenient if the structure of the distribution network is complex, and might be useful in preventing whole-system shutdown in case of failure at a single point.
6. A hot gas defrosting system, including an extra two-way pipeline to distribute the hot gas across the network. The heat required for will be collected from the central facility.
7. (Partially) redundant infrastructure to reduce potential downtime.
8. A third, lower-temperature network for shock freezing.
9. Solar panels to (partially) power the equipment.

A visualization of the consolidated concept can be found in Figure 4.2. Based on the final conceptualization, a short introductory presentation for the participants of the second interview round was created. This presentation can be found in Appendix C.

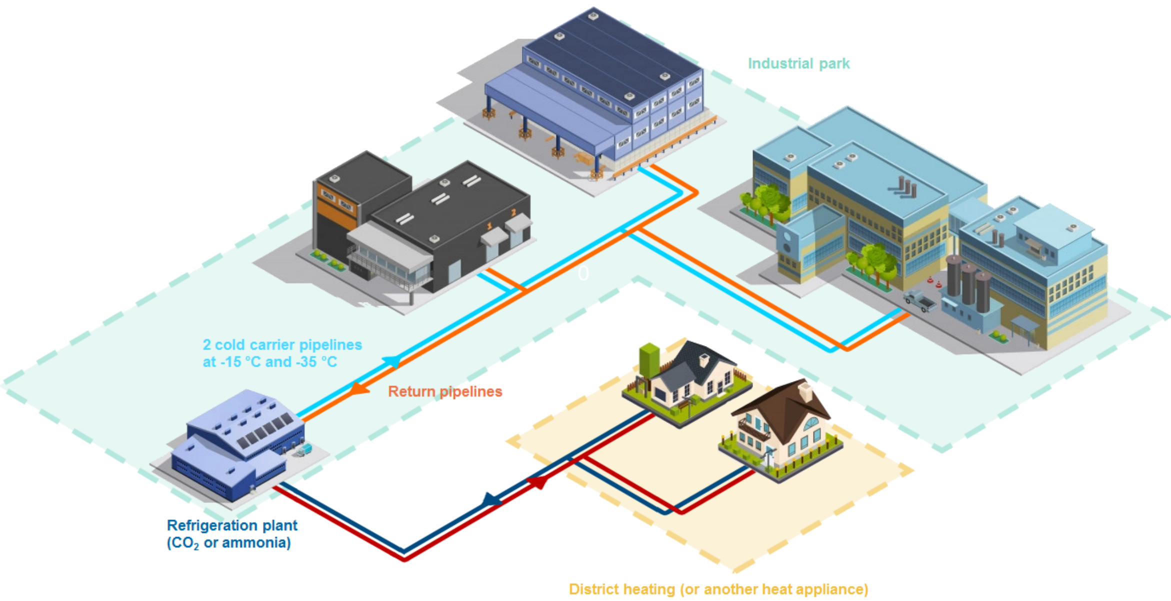

Figure 4.2. Visualization of the final conceptualization.

5 Main interview round and results

This chapter will elaborate on the process of selecting stakeholders for the second round of interviews, as well as the processes of conducting the interviews.

5.1 Stakeholder selection

Before any stakeholder interviews could be carried out, care was taken to select participants that had a relevant position and relevant knowledge to provide qualitative results. Stakeholders from each stakeholder group described by Mortensen & Kørnøv (2019), as well as any additional relevant stakeholder groups mentioned by the participants from the first round of interviews, were selected.

5.1.1 Stakeholder groups identified by Mortensen & Kørnøv (2019)

Mortensen & Kørnøv (2019) carried out a review of relevant IS literature to shed light on the emergence process of industrial symbiosis. They mapped which contextual conditions and which actors are critical in the process, and which roles, characteristics, and activities of actors are associated with success of industrial symbiosis initiatives. Their framework is divided into three phases: (i) *awareness and interest in industrial symbiosis*, (ii) *reaching out and exploration of connections*, and (iii) *organizing*. In each of these phases, they list actors that they identified as determining the successfulness of the respective phase. In each phase the same group of actors returns, albeit bearing different roles and characteristics: *research and education institutions*, *public bodies* (government agencies, regional and local governments, and other public agencies), and *businesses.* In phases 2 and 3, *associations* also play a role, and in phase 3, *consultancy companies* are identified as supplementing or overtaking research and education institutions. In Table 5.1, the different actors are displayed with their respective roles and characteristics, as identified by Mortensen & Kørnøv (2019).

5.1.2 Stakeholder groups identified by 1st round participants

During the first round of interviews, the participants were asked which stakeholders they think would be involved in the implementation of shared refrigeration systems in specific. The results of this inquiry provides a more specific list of stakeholders than the broader framework does, aiding in the selection of interview participants for the second round. The participants indicated that especially the *national government* and *municipal governments* play an important role as public bodies, *business associations* might play a role in the networking process. Businesses that play a role in the implementation of shared refrigeration are, according to the participants, mainly *potential customers, participants of the building consortium* (which will be parties like installation companies, contractors, component suppliers etc.), and *energy companies*. They also indicated that *land owners of industrial sites* stakeholders to be considered, although in practice the land owner of an industrial site will often be the municipal government. These specific stakeholder groups are included in Table 5.1 in italics.

Table 5.1. Actor groups in the industrial symbiosis emergence stage and their activities, based on Mortensen & Kørnøv (2019).

	Phase 1 **Awareness and interest in industrial symbiosis**	**Phase 2** **Reaching out and exploration of connections**	**Phase 3** **Organizing**
Research and education institutes	Develop knowledge Support knowledge sharing Support knowledge dissemination Support knowledge capacity building	Develop knowledge Identify opportunities Monitor developments Disseminate information about developments Contribute to local coordination of activities Provide strategic advice Support knowledge capacity building	Provide knowledge about best practices
Consultancy companies			Provide models, calculations, business case analyses
Public bodies *(national government, municipal governments)*	Provide incentives to innovate and collaborate Provide management support to companies Provide specialized knowledge Encourage symbiotic thinking	Facilitate collaboration Provide funding Provide management support to companies Build trust Build institutional environment	Regulate Issue licenses Provide funding
Businesses *(potential customers, participants of building consortium, energy companies)*	Implement and disseminate IS activities	Coordinate	Implement industrial symbiosis Influence the economic and social context Support other actors Provide funding
Associations *(business associations)*		Coordinate Provide mediation Support network formation	Influence the economic and social context Provide funding Provide knowledge Foster positive interactions and collaboration among actors and their environment

5.1.3 Final stakeholder selection

Stakeholders were found using Google, LinkedIn, corporate websites, news articles, and via recommendations by earlier participants. All contacts were approached through email or by telephone. An email was sent to all participants explaining the theme and purpose of the study, together with a short presentation of the research project and the shared refrigeration concept, as established in Section 4.3.2, in .pdf format to make sure the participants would understand the shared refrigeration system and the purpose of the interview. If the participants replied and agreed to participate, they were sent the interview questions, as well as a consent form to explain the terms and conditions of their participation in the research. They were asked to read the form and either sign it, or provide their verbal consent in the audio recording that was to be made during the interview. The consent form can be found in Appendix B.

23 potential participants from all the previously defined five stakeholder groups were approached to take part in an interview. The specific sub-groups as indicated by the participants of the first interview round were used as a reference. One of these sub-groups, the participants of building consortia that would be involved in constructing a shared refrigeration system, was deemed too diverse to be able to include all relevant parties. Instead, it was opted to approach several people from the installation business, as installation companies typically occupy a central position in construction projects that revolve around refrigeration installations, and have connections with all relevant parties. Therefore, these participants were taken to represent the building consortium sub-group.

Apart from national and municipal governments, provincial governments were added to the list of sub-groups that constitute public bodies, because provincial governments tend to be involved in regional energy initiatives and task forces.

Of the participants that were invited, 13 agreed to participate. According to the privacy guidelines, personal information was removed from the documentations, and they will be referred to with the number 2 followed by the letters A through M. The list of participants of the second interview round can be found in Table 5.2.

Table 5.2. Description of participants for the second interview round.

Participant	Group	Subgroup	Function
2A	Research and education		Retired associate professor of refrigeration technology
2B	Consultancy / Government		Programme manager sustainable heat and cold technologies at an innovation consortium*
2C	Consultancy / Association		Industrial refrigeration consultant, partner at an eco-industrial park
2D	Consultancy / Association		Senior consultant energy and process technology, member of sector association
2E	Government	National	Account manager at a government agency charged with stimulating innovation with knowledge and subsidy programmes
2F	Government	Provincial	Senior environmental policy maker for a provincial government
2G	Government	Municipal	Process manager sustainability at a government cooperative charged with the development of a new agrofood-oriented industrial park
2H	Business	Installation company	Founder/CEO at an installation company
2I	Business	Installation company	Co-owner/CTO at an installation company
2J	Business	Installation company	Service manager at an installation company
2K	Business	Energy company	Area developer sustainable energy systems at an energy company
2L	Business	Consumer	Owner of a medium-sized agrofood firm
2M	Business / Association	Consumer	CEO and COO of a medium-sized agrofood firm** Member of local business association

* This organization is a public-private partnership which has characteristics of both governments and consultancy firms. Hence, the participant was considered to be part of both stakeholder groups.
** This interview was carried out with two participants simultaneously as they felt this would improve the quality of their contribution

5.2 Findings

In the following sections, the results from the second round of interviews are displayed. The first part of the results is structured based on the elements of the framework by Mortensen & Kørnøv (2019). The elements of which this framework consists are *Contextual conditions, Actors, Actors' roles, Actors' activities,* and *Actors' characteristics*. As many results relating to actors contain intertwined and implicit information about roles, activities and characteristics, these results were taken together and displayed under the common header "Actor involvement". In the next chapter, where the results will be discussed, attention will be given to the separate elements of roles, activities and characteristics.

Similarly, while the framework by Mortensen & Kørnøv (2019) makes a distinction between three phases (*Awareness and interest in industrial symbiosis, Reaching out and exploration of connections,* and *Organizing*), many results contain intertwined and implicit information that would make a subdivision in these three phases unsuitable for this chapter. Like the actor properties, attention will be given to the three separate phases in the next chapter.

Note. Any quotations are translations of passages from the original Dutch transcripts.

5.2.1 Contextual conditions

This section displays the results of the interviews from the second round relating to the contextual conditions that are critical for the emergence of industrial symbiosis initiatives according to Mortensen & Kørnøv (2019).

5.2.1.1 Policy

Several participants state they do not think there are barriers to the emergence of shared refrigeration initiatives given the current state of government policy, laws and regulations (2F, 2H, 2I, 2M). Another participant notes that there might be some policy barriers, but that pilot projects will not face any legislative problems, and if those are successful, governments might work to remove policy barriers (2B).

Other participants see some practical policy barriers. The Warmtewet (Heat law) includes an hourly penalty for failing to deliver heat for a period longer than 6 hours (2C). Building permits require a BENG calculation, which is to a high degree determined by the calculation of a CO2 footprint, which is challenging, time-consuming and expensive for nonstandard projects like shared refrigeration (2C). This legislation does not apply to industrial refrigeration, but couplings to offices or heat networks, which will likely be present in shared refrigeration systems, will result in juridical hassle (2C).

Several participants argue that there could be some policy barriers in a later stage of the development process that would pose potential problems to large-scale sharing of refrigeration. This includes safety laws concerning natural refrigerants (2A, 2F, 2H, 2I). However, one participant argues that although safety laws concerning natural refrigerants are present, these might actually work in favor of shared refrigeration systems, as potentially hazardous equipment is moved out of company buildings (2M).

Some participants note that there are many opportunities for heat and cold grids and new business models (2E, 2G), but these are still premature, for a part due to a lack of dedicated policy

(2E). A participant notes that such dedicated policies are being developed, but that they are subject to heavy discussion as they will impair the freedom of entrepreneurs and form a burden to them (2G). Other participants, in turn, argue that they would not mind the government steering the industry toward sustainability with more forceful legislation (2H, 2J).

One participant notes that although there are many sustainability laws, the monitoring and enforcement is too limited, which they attribute to a lack of government personnel (2B, 2J). For example, there is an obligation to do all energy-saving investments that have a payback period of less than five years (2B, 2M), but the government does not have sufficient capacity to rigorously enforce it (2B). The participant notes that there is an obligation to check the energy consumption of air conditioning systems once every five years under the Energy Performance of Buildings Directive (EPBD), but that a similar check for refrigeration equipment does not exist, while they are generally more energy-intensive (2J).

One participant sees an incentive growing as firms will be forced to abandon natural gas as an energy source by 2030 (2E). Therefore they are starting to evaluate alternatives. Electricity might not be available due to congestion problems, so efficient heat and cold systems could be both practically and financially more attractive (2E). Sustainability measures are becoming stricter for office buildings as well, requiring at least Energy label C from January 1st 2023 (2E).

5.2.1.2 History

Projects like shared refrigeration executed on a large scale, were not known to all participants (2D, 2F, 2H, 2I, 2J[7]). However, one participant notes that similar projects concerning sharing of cold energy already exist (2B). Similar initiatives, but using heat or steam, are present on a larger scale (2F, 2G).

Similarly structured systems where there is a central refrigeration network within one complex exist, from which lessons can be drawn (2J). These are for example flower auction buildings (2C, 2J), buildings with a combined business and residential function (2J), shopping malls (2J), and large businesses with internal refrigeration networks (2J).

Prior collaborations through local business associations are present in many industrial parks, but the themes on which collaboration takes place are much more basic than industrial symbiosis (2E, 2L, 2M). Besides, many businesses are not interested in actively participating in those associations (2M). One participant recalls having been based at two industrial parks over his career, and finding the collaboration through the local business associations “almost at zero point” (2M). He exemplifies that the business association of which he is currently part has 22 members out of an estimated 110 businesses that are located on the park (2M).

5.2.1.3 Funding

A majority of participants agree that funding should not be an issue, noting that interest rates are low and plenty of investors would be willing to invest in sustainable technologies. This is of course provided that the technology has a serious likelihood to be successful (2A, 2C, 2D, 2E, 2G, 2H, 2I, 2J, 2L, 2M). Currently, many funding institutions offer benefits if the money is spent on sustainability

[7] Participant 2C mentioned that there is a similar project (Coolinq) which is being explored in the town of Urk, but that he did not know whether the project had been a success. This project is in development. The project leader was contacted for an interview, but was unable to participate.

improvements (2G). One participant mentions that so-called Green Deals might be attractive constructions, where businesses, investors, public bodies, and banks join forces to lift the project off the ground (2G).

Financial assessments in refrigeration technology are in the 10-15 year range (2C). Due to the relatively long horizon and the high front-end investment costs will lead to unprofitable front-end investments[8] (2B). The combination with a rather short term focus and a relatively fast-changing technology and policy environment might pose a threat to the feasibility (2B). The Ministry of Economic Affairs is working on a solution (2B).

There are no specific subsidies for refrigeration (2D), although refrigeration is not excluded in subsidy regulations (2F). Combinations with heat pumps are more likely to be entitled to subsidies (2D).

SDE++ is a possible subsidy to cover the unprofitable front-end investments for waste heat reusal (2E). This subsidy is only granted to initiatives that prove to lead to a significant environmental improvement, meaning that the environmental benefits should therefore first be evaluated (2A, 2C, 2K). A problem might arise in that SDE++ subsidy for heat pump solutions requires the number of operation hours of heat pumps to be above 5000, which is not achieved in most food companies and built environment, thus making the project not eligible for this subsidy (2D). However, the government is working on changing it (2D). Another subsidy that is available for heat and cold systems is VEKI (2E). However, many of the projects are turned down because they do not achieve a large enough reduction in CO_2 emission (2E).

Finally, it might be unclear if the project is entitled to subsidies depending on the project's legal structure (2I), and if there would be an advantage compared to smaller scale solutions, as subsidies available for these systems are also available for smaller individual systems (2C). In terms of large-scale benefits, one participant mentions that there are tax advantages for energy consumption which is more than 10 million kWh annually (2C).

A potential problem lies in that most current subsidies are for implementation, and not for research and investigation (2D). It is important to find local subsidies to fund this phase, as businesses might be reluctant to fund something that has not been adequately researched (2D). However, it is also more difficult to find subsidies for premature innovations, as innovations are required to have a high so-called Technology Readiness Level (TRL) in order to receive subsidies (2F).
One participant argues that subsidies should not be a trigger (2D). Rather, the system should be profitable by itself (2D). Another participant mentions that he sees a change in mindset of the industry (2E). In the past, the industry would turn to the government to subsidize any unprofitable front-end investments (2E). The current mindset tends to be more independent: the industry tries to reduce risk-based pricing by finding solutions for risks they may face, which decreases the unprofitable front-end investments (2E).

Moreover, although sustainable heat pump technology is very expensive, there are trends of increasing mass production and continuous innovation, leading to lower prices and better performance of heat pumps (2E). This could make the business case of a combined heat and cold system more interesting (2E).

[8] The term used by the participant in Dutch is "onrendabele top", which is the difference between the front-end investment and the business value, when the former is higher than the latter. There is no literal English translation for this term.

Also, an incentive is growing as firms will be forced to abandon natural gas as an energy source by 2030 (2E). Therefore they are starting to evaluate alternatives. Electricity might not be available due to congestion problems, so efficient heat and cold systems could be both practically and financially more attractive, especially as the demand for cold in office buildings is expected to grow (2E). Due to these dynamics, there will be several natural investment moments between now and 2030, and between 2030 and 2050 (2E).

5.2.1.4 Infrastructure

Several participants confirm the need for a good collaboration platform (2A, 2J). A participant notes that seminars and workshops are good ways to spread information in the emergence phase, and that these are already taking place (2D). According to two participants, face-to-face meetings are the best way to meet (2A, 2C). This is important to build trust, the formation of which is crucial (2C). Physical meetings are even more important in this case because of the nature of agrofood entrepreneurs (2C). Dedicated platforms will have to be developed specifically for each project (2H, 2J).

Participants argue that sector business associations are not a suitable platform for this (2H, 2I), as members are spread over the whole country (2H) and have fear of competitive threats, because members of sector associations are usually competitors (2F). Businesses therefore tend to be careful in sharing information with other members of the sector association (2F). Participants argue that local associations are more suitable platforms (2G, 2H, 2I, 2M).

However, these local associations are not always present. One participant notes that not all industrial parks are well-organized, in the sense that they have an active local business association, a park management, or are a so-called BIZ (*Bedrijven Investeringszone*, Business Investment Area) (2B). Other participants confirm that existing local business associations are usually poorly organized and unable to organize complex initiatives (2E, 2L, 2M). Dedicated platforms will have to be developed specifically for each project (2E, 2G, 2I, 2J, 2M). One participant argues that the formation of these collaborations depends on the degree of urgency, which he argues is currently low (2K).

5.2.1.5 Time

Some participants mentioned that a feasibility study for a project like this could start at any time, and that timing is not the determining factor (2G, 2H, 2M). However, participants note that the project will have a long term planning (2A, 2B). The long term investment horizon might be a challenge because businesses might not always be able to commit themselves for a period longer than ten years (2E). This creates uncertainty in the profitability and continuity of the system (2E). It also requires patience of stakeholders, which will depend on the advantage they get from it (2A, 2G).

The current environment is a favorable one for new sustainable concepts (2A, 2B, 2D, 2J). Circularity and shared services are high on the agenda, and the energy transition forces business and governments to find new, sustainable and collective forms of energy (2D, 2E). The investment climate is good (2J). The congestion problems that plague the electricity network form an opportunity to think out of the box, which might be favorable for shared refrigeration initiatives (2E). Natural investment moments are expected to arise until 2030, when natural gas will be abandoned, and thereafter between 2030 and 2050, after which date the country's CO_2 emission is scheduled to be zero (2E).

However, one participant notes that these natural investment moments are different per company (2E). The participant adds that, as the heating and cooling demand on an industrial park is often skewed, the initiative would probably only be viable if coupled to a heating grid in a residential area that is newly built, or already exists but is ready for an energy transition (2E). Another participant notes that governments sometimes make plans to redevelop an industrial park and therefore buys out the businesses, and that such moments make for opportunities to start such initiatives (2A). However, these opportunities are not always available (2E), making the occurrence of opportunity windows scarce.

A large challenge can be found in the misalignment of arrival times of the businesses in a new industrial area. Developing a shared refrigeration system requires mapping the demand profiles of the participants, which more or less turns into a guess if the participants have not yet been identified (2C, 2E, 2J).

Another participant contradicts this argument, stating that calculations regarding refrigeration demand are predictable enough to a degree that this would not be a problem (2H). Another participant confirms this, but points out that these estimations are only practically feasible if the general temperature demand is known (2J). The temperature demand is connected to the type of company, and if there are not enough companies to fill the park, other companies might be attracted which have different refrigeration demands (2J). One participant who sketches the same situation sees opportunities in creating two-stage refrigeration for those exceptions, where additional refrigeration equipment is installed to account for the different demand (2D).

Delayed arrivals also lead to large unprofitable front-end investments (2B, 2C, 2E, 2I, 2K, 2L, 2M). Another participant points out the risk of economic decline during the building phase, which may slow down the filling of the industrial park even more (2J). Although one participant argued the investment climate is good, he notes that it might be challenging to find sufficient funding for these unprofitable front-end investments (2B). Two participants suggest that making the equipment and the network scalable would be a potential solution to the problem of delayed arrival (2B, 2M).

5.2.1.6 Geographical proximity

One participant mentions that geographical proximity helps in that businesses can be more in touch with each other through local business associations, which have meetings from which new local initiatives might arise (2D). There are certain areas where companies that have a demand for refrigeration are clustered (2D, 2G). The national Heat Atlas (*Warmteatlas*) could be a tool to find out where these are (2D). However, one participant thinks the largest share of potential participants is scattered over the country (2J). While he adds that this fragmentation need not be a problem (2J), another participant notes that moving existing businesses is difficult, especially in agrofood businesses (which are among the companies with a large refrigeration demand), as there are many building-specific investments that are lost when moving to another location (2L).

One participant argues that geographical proximity and knowing each other helps, but it also works if businesses are connected via associations through which they meet each other regularly (2C). Another participant adds that temporary geographical proximity in meetings has proven to be effective for the creation of symbiotic partnerships (2E).

One participant argues that knowing each other might actually work adversely in some situations, because of potential negative past experiences or fiercer rivalry (2M).

5.2.1.7 Knowledge of each other's pool of resources

Knowledge exchange is happening continuously, although currently it is undergoing a decrease due to pressure on the industry resulting in a lack of time and dedication (2D). One participant notes that he is seeing a repetitive motion in the knowledge that is being exchanged, and attributes this to new generations of people arriving in the business world (2D).

Sector business associations and some local business associations organize regular meetings through which sharing of information is happening (2A, 2D). One participant notes that he would find it strange if businesses would not know each other's needs in terms of refrigeration (2A). These associations would provide a suitable platform to share information in the event that a shared refrigeration initiative would be explored (2A).

However, other participants note that knowledge sharing among businesses is still suboptimal. Within a sector business association, there is less sharing than in associations that comprise a diversity of businesses, due to competitive threats (2F). Sector business associations do collaborate if they collectively want to go in a certain direction, but knowledge exchange stalls when competitive advantage is at stake (2F). Businesses would not share more than their demanded refrigeration capacity and perhaps their demand profile, due to perceived competitive threats (2C). Several participants noted that there is a culture of distrust of others among incumbents (2B, 2J, 2K) even though their businesses might not completely overlap (2K), but that young businesses and larger companies tend to be willing to share more information (2J).

Nevertheless, some participants noted that they do not think refrigeration capacity data is sensitive information, and businesses would not be afraid of competitive threats when sharing their demand profiles (2H, 2L).

One participant notes that he thinks the government has insufficient knowledge of what businesses need in terms of refrigeration (2M), which is to a certain extent agreed with by another participant (2G). One participant thinks the government has no role in mapping refrigeration demands to find opportunities for symbiosis (2I).

However, other participants stress that the government is actively stimulating the emergence of sustainable collaborations in the fields of heat and cold energy. For example, a national innovation programme is in the process of being created, through which information and experiences concerning innovative and sustainable projects can be distributed easily throughout the country (2B). This sharing already occurs somewhat on a regional level (2B), for example through Fieldlab experiments, which are also meant to serve as demonstration projects for the entire industry (2F).

There has been an attempt to map waste heat emissions in the Netherlands in the form of the Heat Atlas (*Warmteatlas*), from which can also be derived what waste heat is generated by refrigeration equipment (2D). One participant, after arguing such a scan would be beneficial, notes that he thinks there has not been such a scan (2L). However, the participant does not see the perceived lack of a scan as a barrier (2L).

In certain situations, governments engage in partnerships with commercial parties that serve as central advisory organs for a range of stakeholders that wish to settle in a new industrial park, thereby defragmenting the information streams (2G). This allows for more integrated solutions, as there is one advisory organ overseeing all dynamics (2G). This role can also be fulfilled by a local business association or a park management (2G). However, other participants note that local business associations tend to focus on things much more basic than industrial symbiosis (2E, 2M, 2L), and many businesses are not interested in actively participating in those associations (2M). Two participants note that they think businesses in industrial parks do not know what their neighbors are doing concerning refrigeration (2B, 2D).

Installation companies see themselves as having knowledge of refrigeration demands of businesses (2H), and argue that they often know even more what customers need than the customers themselves (2I). However, other participants mention that not all installation companies have the knowledge to provide sustainable and integrated solutions (2E, 2J), and it might be difficult for businesses to find the companies that do (2E). The participants active in installation companies admitted that they do not interact with research and education institutions (2H, 2J), but are stimulated to do their own research and development through certain subsidies (2H). The participants note that the innovative thinking only resides in the top management (2H).

Moreover, a problem lies in that the electricity world and the heat world are two separate worlds that do not interact sufficiently with each other, resulting in a lack of couplings between machines, even in the same buildings (2E). Suppliers tend to focus on their own products and do not offer integrated solutions, forwarding the task of coupling waste streams to the consumer, who does not have the knowledge or capacity to do it (2E). One participant attributes this to the increase in difficulty for the supplier that such couplings would entail - couplings to machines not supplied by the same supplier would increase the perceived risk of machine failure and lower reliability. Suppliers do not want to get themselves into those kinds of problems and therefore do not offer these integrated solutions to their customers, leaving the customers with the illusion that they received the best possible result (2E).

5.2.2 Actor involvement

This section displays the results of the interviews from the second round relating to the actors, actors' roles, actors' characteristics, and actors' activities that are critical for the emergence of industrial symbiosis initiatives according to Mortensen & Kørnøv (2019).

5.2.2.1 Research and education institutions

Research and education institutions have an advising and supporting role (2A). They focus predominantly on highly innovative projects. As shared refrigeration does not entail a highly innovative technology, universities will not play a role in this (2A). However, students may be interested in working on the project (2A, 2J).

5.2.2.2 Consultancy companies

Consultants are already involved in many sustainable collaboration initiatives (2C). Consultancy companies and government consultancy bodies have a large network of customers and can play a large role in information sharing through periodical meetings, seminars, workshops, and innovation programmes (2B, 2D). Many participants agree that consultants have a clear overview of existing and novel technologies, laws and regulations, and subsidy opportunities, and are therefore in the position to fulfill a missionary role, and take the lead in projects (2A, 2B, 2C, 2D, 2H, 2I, 2J). However, participants also note that consultants are not project developers, so their role is usually limited to the first phase of a development process (2B, 2D).

5.2.2.3 Governments

Participants note that governments are willing to support initiatives if they increase sustainability and have economic advantage (2E, 2F, 2G). One participant notes that he thinks that government policy that steers towards sustainability is a driving factor behind innovation (2J).

The national government provides assistance to both businesses and regional and local governments that lack knowledge of technology or legislation, a network, finances, to engage in sustainable initiatives (2E). The national government can provide the linking pin between public and private parties, for example in situations where a municipal heat network is fuelled by industrial waste heat (2E). The national government takes initiative and a missionary role in making businesses aware of opportunities for becoming more sustainable, bringing different parties together, assessing and mapping opportunities, sharing experiences from other projects, and instigating project formation through guidance and funding (2E). After the initial phase, the role of the national government decreases and becomes just advisory (2E).

Provincial governments occupy an in-between layer that provide subsidies, give out permits, monitor and enforce (2F). Provincial governments try to stimulate sustainable innovation, and help strategize for regional energy infrastructure projects (2F). One participant thinks that the provincial government will act more or less reactively, but if there is potential, they can actively assist in regional pilots or Fieldlabs (2F).

The municipality has a facilitating and coordinating role, and it can provide funding and capacity (2G). Participants describe that municipalities proactively ask businesses about the possibilities of using their waste heat (2D, 2G). Municipal governments facilitate the collaborative process by organizing meetings, discussions, information sessions (2G). If there is potential, municipalities can establish other entities together with commercial parties, like a local business association, a park management, or a BIZ (2B, 2G).

Another participant notes that municipalities also play an important role because they control the zoning plan, which might have to be adapted for new appliances like a shared refrigeration system (2H). He argues that because of their important role, a municipality can make or break a project (2H). Several participants argue that the municipality should take the role of organizing and presiding over a dedicated association of parties involved in the development of shared refrigeration (2A, 2B, 2M).

Several participants mention that businesses expect the government to provide subsidies for sustainable projects (2E, 2F, 2H, 2I, 2J, 2M). One participant notes that he thinks providing subsidies is the most important role played by the government (2I). One participant notes that he does not trust the current government due to its instability (2M). He notes that "if the government wants us to go this way, they should subsidize us maximally" (2M). The participant sees the government as one of the parties investing in the realization of the project (2M). However, a government-affiliated participant notes that the government will play a role in facilitating and stimulating cooperation, but will not be likely to carry risks or develop the system (2G).

Despite this, a participant notes that the national government is working on policy and regulation to find solutions for covering unprofitable front-end investments (2B), and another participant mentions noticing a shift, explaining that businesses are increasingly trying to think in a problem-solving fashion, decreasing the need for subsidies (2E).

5.2.2.4 Businesses

Businesses are always looking for advantages for their own company (2A, 2F, 2G, 2H, 2I, 2K, 2L), so if there is an advantage in shared refrigeration, they would be willing to engage in it (2A, 2L, 2M). If the advantage is not clear, this might be problematic (2A, 2I, 2K, 2L). The fact that they are focused on their own benefits may lead to suboptimal information sharing and unwillingness to collaborate (2F, 2G). One participant illustrates this characteristic by noting that "you virtually have to make something mandatory to get them to do it" (2F). Several participants implicitly express the same sentiment of policy being the only way to get businesses to engage in sustainable collaborations (2H, 2J, 2M).

One participant notes that businesses do not always engage in collaborations because of financial gains (2D). Many businesses outsource services because they do not have to worry about them anymore, even though it is less profitable (2D). Businesses tend to be reluctant or simply unable to engage in activities that are not their core business (2D, 2E, 2I, 2L), so one participant thinks that it is unlikely that they would be actively involved in the research and development of the system (2D). Some participants attribute the somewhat narrow scope of businesses to a lack of personnel and capacity (2D, 2I, 2L).

The participants from business mentioned they value sustainability (2H, 2I, 2J, 2L, 2M). Businesses are open to talk about sustainable initiatives (2L, 2M), but will only engage in them if they are clearly advantageous for them as well (2L, 2M). This advantage could be financial, but also in terms of an improvement in the public's perception of the business (2L). Another participant notes that businesses, despite their openness toward sustainability, tend to have limited knowledge of the possibilities of sustainable collaborations (2E, 2I). Not only end users, also installation companies tend to stick to more traditional technologies, due to a lack of knowledge and a shortage of personnel, one participant argues (2J). Participants think that installation companies are not in the position to take the lead in the development process (2H, 2J), but that they would take a role in the construction and maintenance of the system (2H), and that installation companies in both heat and cold technology can take advisory roles in the development process (2I).

Businesses that actively take the lead in initiatives are those that look further than their current business model (2E, 2K). But these are exceptions, as the largest part of businesses does not feel the urgency to do so (2E, 2K). One participant from business also notes that many businesses do not feel the urgency to collaborate (2M). Businesses that feel connected to their environment, for example long-established local companies and family businesses, are more likely to actively participate in initiatives (2B, 2K). This also applies to smaller branches of some multinationals (2K, 2L).

However, it is not always the end user himself who develops industrial real estate (2G, 2K). This is often done by investors or real estate developers, whose main and virtually only objective is to maximize profits (2G, 2K). These parties have an interest in making the buildings as versatile as possible, so their tenants can do whatever they want (2G). Creating a mandatory dependence on a shared refrigeration system impairs this versatility and will therefore likely not have the support of these real estate developers, two participants argue (2G, 2K). Moreover, one participant argues that real estate developers do not have the aforementioned connection with their environment and are therefore less likely to actively participate in sustainable initiatives (2K).

Businesses that form potential partners are typically led by people who value physical meetings, which are necessary to develop mutual trust (2C). This mutual trust is crucial (2C, 2E), for a part because the average SME owner is not “a spreadsheet person” (2C), entrepreneurs are emotional, like to do things their way, and want to be in control (2K, 2M). One participant notes that he thinks these characteristics might be detrimental to the success of collective initiatives (2K).

Two participants note that they imagine a dominant consumer of a future shared refrigeration system as having to take the lead in the initiative (2L, 2M). Small businesses have too little power to lift the project off the ground (2L). Two participants agree that businesses (or business associations) should be the ones with the developing and investing role (2G, 2J). One participant from business mentions he would consider investing in the system, and potentially playing a role in the exploitation, if the business model is viable (2M).

One participant sees a role for a large energy company (2H), as large energy companies have many resources (2H, 2K). However, shared refrigeration is currently not regarded as a viable concept by energy companies (2K).

5.2.2.5 Associations

Several participants think that business associations could take developing and investing roles (2G, 2J). Participants note that existing sector business associations can facilitate the emergence of shared refrigeration initiatives through their interactions with their members (2A, 2H). Sector business associations are actively stimulating innovation through project groups (2D). However, businesses tend to be careful in sharing information with other members of the sector association, as they fear losing any competitive advantage (2F). Some participants think that sector business associations will not have a role in the process (2I).

Local business associations would play a crucial role in the emergence of shared refrigeration initiatives (2C). However, local business associations now focus predominantly on collective procurement of things like telephony, internet, security, and solar panels, which is much more basic than things like the development of shared heat and cold networks (2E, 2L). Local business associations do not have the means, the capacity, the knowledge, and the degree of management to realize such projects (2E, 2L). Participants argue that new business associations should be formed at an early stage of the project, with parties that together can complete the business case (2E, 2I, 2J, 2M). Because the business case development does not necessarily involve end users, it might be a challenge to get them to cooperate (2E). Another participant notes that the willingness to participate might be there but that it differs from business to business (2M). Furthermore, if the heat cannot be kept within the industrial park, even more separate parties have to cooperate (2E). The result is a small scope but a very large investment (2E).

Other participants argue that the government should be involved in local associations, stating that governments can stimulate businesses to bring topics like shared refrigeration up for discussion, and subsequently finance some feasibility studies (2B). Governments are the ones to take the role of conducting first scans (2B), and organize Fieldlabs that can serve as demonstration projects (2F).

The municipality could take a facilitating and coordinating role, and it can provide funding and capacity (2G). If there is potential, municipalities can establish other entities together with commercial parties, like a local business association, a park management, or a BIZ (2B, 2G). Those associations can take the role of gathering different parties together (2G). This is not a role for a municipality as there is a significant gap between the municipalities and individual entrepreneurs (2G). Such an association can also coordinate the knowledge flows and monitor opportunities (2G). The creation of similar associations already takes place when new industrial parks are being developed (2G).

One participant notes that he believes only such a public-private partnership can take the lead (2E), stating that he thinks he government is in a good position to spark interest and to bring different parties together, but will not be able to finance the project, which will be the task of commercial parties (2E). The government will act as an independent, stabilizing party that generates trust among the stakeholders, who will be less likely to fear they are being scammed (2E).

One participant notes that membership of business associations dedicated to developing shared refrigeration should be mandatory for businesses in the park (2M). There should be independent members as well, like government representatives and technical experts that can provide clear leadership and advice (2B, 2M). One participant fears chaos if the association will be led by entrepreneurs alone (2M). The participant expresses the concern that friction might arise in newly created business associations over costs and benefits (2M).

One participant notes that he thinks consultancy companies together with an industry party that have practical experience and a plan that has been tested could also take the lead (2J).

5.2.3 Barriers to future engagement

This section displays the results of the interviews from the second round relating to the barriers found in scientific literature as described in Section 2.3.

5.2.3.1 Insufficient finances or financial incentives

Many participants argue that there are enough financing opportunities for initiatives like shared refrigeration (2C, 2D, 2E, 2G, 2K). Participants note that the long length of the financing horizon might be an obstacle for investors (2B, 2L, 2M).

However, almost all participants note that a financial incentive must be present, and that it can only be clear whether there is an incentive after a business case analysis has been completed (2A, 2B, 2C, 2D, 2E, 2F, 2G, 2H, 2I, 2J, 2L, 2M). This is not an easy task (2B, 2D, 2L, 2M). One participant states he does not expect that there will be profit (2K). Another participant notes that a business' energy bill is usually relatively small compared to its total costs, and notes that businesses are unlikely to invest so much money in something that will affect a minor part of the balance sheet (2B).

One participant does expect that there will be financial benefits to a shared refrigeration system (2M). Another participant notes that a partial incentive may occur due to the current energy transition and the congestion problems in the electricity network, forcing businesses to look for other business models (2E).

5.2.3.2 Lack of technological knowledge or codification

Many participants state that they think there is sufficient technological knowledge to realize a shared refrigeration system (2A, 2B, 2C, 2D, 2E, 2F, 2G, 2H, 2I, 2J, 2K, 2L). However, one participant notes that the technological knowledge is fragmented and needs to be assimilated (2G). Another participant mentions that consumers do not have sufficient knowledge about refrigeration technology and sustainable solutions (2M). A third participant notes that the level of technological knowledge differs per organization, and that although many businesses have much knowledge about traditional applications, there is less technological knowledge about novel and innovative applications (2K).

5.2.3.3 Inadequate provision of information

Many participants argue that there is currently a lack of information provision (2B, 2C, 2D, 2G, 2H, 2I, 2J). Participants note that there has not been much attention for sustainable refrigeration solutions yet (2B, 2D).

On the other hand, three participants do not see specific problems concerning inadequate information provision (2K, 2L, 2M). One participant states that he thinks sufficient communication channels are in place to share information (2A), while others state these channels need improvement (2G).

5.2.3.4 Lack of time to invest in IS engagement

Several participants mention a lack of time as a restraining factor (2D, 2I, 2J). One participant notes that larger companies might have more time to spend on innovation, due to a large availability of personnel, with which smaller businesses tend to struggle (2I). Many other participants connect a lack of time to the level of priority that sustainable innovation has within a firm, which they state depends on the financial advantages that a shared refrigeration will hold (2A, 2B, 2G, 2H, 2K, 2L). Two participants note that sustainable ambitions might also be a reason for businesses to invest more time in innovation (2H, 2K).

One participant stresses that businesses usually want things done as soon as possible, and that the complicated technical, financial, and perhaps legal aspects of shared refrigeration will require a long time that might not fit in the normal development process of new industrial real estate (2C).

One participant from the business stakeholder group mentions that their company does not have a lack of time to spend on innovation (2M).

5.2.3.5 Difficulty finding suitable locations for implementation

Many participants mention that difficulty finding suitable locations for implementation would be a barrier for shared refrigeration technology (2A, 2C, 2E, 2F, 2G, 2I, 2J, 2K, 2L, 2M). Participants mention a general lack of new building sites (2I, 2L, 2M), the lack of clustering of businesses with a similar temperature demand (2C, 2L, 2M), unwillingness of potential partner businesses to relocate their businesses to the new site (2A, 2L), or the difficulty finding locations where all vital elements (sufficient refrigeration demand, sufficient heat demand, a stable long-term appliance base) come together (2E, 2F). Some participants also mention the importance and difficulty of finding a location where the system can be fully operational as soon as possible (i.e. where the "filling up" of the industrial site is completed within a short period of time), to reduce the unprofitable front-end investments as much as possible (2E, 2L).

One participant explains that he is involved in the development of a new site where similar businesses are actually clustered together, and notes that even with this clustering, implementing sustainable concepts remains a complicated issue (2G).

Other participants mention that finding suitable locations for implementation will not be a determining barrier, if adequate instruments like scans are used to map opportunities (2B, 2D, 2H).

5.2.3.6 Lack of commitment by firm leaders

Some participants argue that the level of commitment of firm leaders differs from firm to firm (2A, 2G, 2H, 2J, 2K, 2L). One participant argues that the level of commitment depends on the type of company and the values that drive it (2G). He exemplifies that family enterprises tend to be more committed to care for their buildings, environment and personnel, and therefore also tend to engage more easily than others in long-term, sustainable innovations (2G). Another participant argues that the level of conservativeness is also a determining factor for the level of commitment, stating that more conservative firm leaders tend to stick to the more traditional technologies and mindsets (2H).

Three participants argue that the level of commitment depends on the economic advantages that shared refrigeration offers or is expected to offer (2A, 2B, 2L). One participant from the business stakeholder group (who expects economic advantages) mentions being interested, and states a lack of commitment would not be an issue (2M).

Others argue that a lack of commitment is in general present for several reasons: firm leaders do not like to be dependent on a central system (2C), they have a lack of time (2D), or they have a lack of knowledge and insight (2D). One participant argues that firm leaders would want to participate, but that they would not bother to put active effort in the implementation process (2I).

5.2.3.7 Lack of public awareness and interest

Several participants argue that this is a business-to-business concept, in which the general public has only a minor influence, or no influence at all (2A, 2C, 2G, 2I).

Some participants argue that there is a lack of awareness and interest (2D, 2F, 2H, 2K, 2M), and that the public might be worried about the effects of a shared refrigeration system or an attached district heating network on their neighborhood, which might have effects on the success of the concept (2D, 2I, 2M). Two participants expect that with adequate information provision, the public would probably embrace such sustainable concepts (2H, 2I). One participant states that he expects that an increase in public awareness and interest will result in societal pressure on businesses to engage in the initiative (2H).

Three participants mention that they see many collective initiatives arising as the energy transition is taking shape, indicating that the general public is aware of and interested in sustainable innovations (2B, 2E, 2J). Another participant similarly states that there is sufficient awareness and interest as long as the concept increases sustainability (2L).

5.2.3.8 Having a short-term focus

Several participants think that businesses tend to keep a short-term focus (2A, 2B, 2D, 2E, 2F, 2J). Participants indicate that this is problematic because a shared refrigeration system might only be profitable in the long term (2F, 2G). One participant stresses the fact that both shared refrigeration and heat networks require the presence of a stable, long-term source, which businesses are probably not able to guarantee as they tend to plan at most 10 years into the future, which is not enough for concepts of this scale (2E).

Other participants do not think a short-term focus kept by businesses is a barrier for shared refrigeration technology (2C, 2I), while others indicate that this would differ per business (2K, 2L, 2M).

5.2.3.9 Distrust of potential symbiotic partners

Some participants do not think there is distrust between potential symbiotic partners in the context of a shared refrigeration system (2A, 2L), noting that businesses will only be consumers, that they do not have to share essential business information, and therefore do not have a reason to mistrust each other (2A, 2L).

Other participants state that they do think there is distrust between parties (2C, 2D, 2F, 2G, 2J, 2K, 2M). They state a possible fear that one company profits more than another (2D, 2M), that the operator of a shared refrigeration system does not live up to his delivery promises (2G, 2J, 2K), or that partners quit the network, resulting in higher costs for the remaining partners (2M). However, some participants argue that with solid agreements, this distrust can likely be reduced (2D, 2H, 2I, 2L).

One participant notes that distrust of the government might be an issue, especially in the current situation where policy is relatively rapidly changing and the government is perceived as being unstable and unreliable by some (2M).

5.2.3.10 Fear of output quality issues

Several participants note that fear of output quality issues is an important issue, as a system failure might have a significant impact on the production of firms, especially agrofood businesses (2A, 2B, 2D, 2F, 2G, 2I, 2J, 2K, 2L, 2M). They note that businesses might fear being dependent on a central system as they do not have control over their own equipment (2A, 2F, 2I, 2J).

Some participants argue that this barrier can be reduced if clear agreements are made in advance about what will happen if a system failure occurs (2B, 2C, 2D, 2G, 2H, 2J, 2L, 2M). Two participants draw a parallel with electricity networks, which businesses also use, despite those also being collective services that have a risk of downtime (2H, 2L).

5.2.3.11 Fear of not being worth the investment

Participants indicate that potential participants might fear the investment will not be profitable (2A, 2C, 2D, 2G, 2J). One participant notes that there might be a fear that the business case will collapse if one or more partners end their participation (2C). Several participants indicate that they think this barrier depends on profitability calculations, and that it need not necessarily be considered a fear (2A, 2B, 2G, 2H, 2I, 2K, 2L, 2M).

5.2.3.12 Lack of cooperation between public and private sector

Some participants think there is insufficient cooperation between the public and private sector (2D, 2F, 2M), stating that parties are not actively initiating interactions (2D), that there is insufficient information sharing in existing collaborations (2F), and that they feel the government is unreliable and unstable, while unidirectionally giving orders (2M). Another participant recalls from experience that governments are sometimes reluctant to engage in public-private partnerships (2B). One participant notes that in large municipalities where several different departments would be involved in the project, friction might occur within the government apparatus (2A).

Other participants do not think there is a lack of cooperation between the public and private sector for sustainable initiatives (2C, 2H, 2I, 2L), or state that in occuring cases, setting up such a cooperation is doable (2G, 2J).

6 Discussion

In this chapter, the results of the main round of interviews will be discussed in order to advance to answering the last two subquestion of this research, as well as the main research question of the current thesis: *How can the implementation of shared refrigeration among SMEs in Dutch industrial parks be facilitated?*

6.1 Interpretation of results

This section will discuss the findings of the main interview round in the light of the two frameworks that were used to guide the research, as well as the rest of the scientific literature that was reviewed in Chapter 2. The first seven subsections will elaborate on the contextual conditions from the framework of Mortensen & Kørnøv (2019), as well as the barriers from the list described in Section 3.2.2. The subsequent subsections elaborate on the actors and their roles, characteristics and activities.

A summary of the extent to which the contextual conditions are enabling according to the different participants can be found in Table 6.1. Whereas participants tend to agree on whether some contextual conditions are enabling or not, the results indicate that there are still some differences in their views. Subsections 6.1.1 through 6.1.7 will discuss these differences and analyze them in the light of the three-phase model by Mortensen & Kørnøv (2019). **Note.** If one or more of the phases are not mentioned and elaborated on in any of the subsections, this is because in the framework of Mortensen & Kørnøv (2019), the respective factor is not mentioned to be important in that phase of IS emergence.

A summary of the extent to which the barriers from the list described in Section 3.2.2 are present according to the different participants can be found in Table 6.2. Whereas participants tend to agree on whether some barriers are present or not, the results indicate that there are still some differences in their views. These differences will be discussed in relation to the contextual conditions in Subsections 6.1.1 through 6.1.7.

Subsections 6.1.8 through 6.1.10 will provide a discussion of actor roles, characteristics and activities that were described and envisioned by the participants during the interview in the light of the framework of Mortensen & Kørnøv (2019). Although these factors tended to be in line with those described in the framework, the results indicate that there are some differences, which will be discussed in said sections.

As can be seen in Tables 6.1 and 6.2, participants provided several nuances with regard to the barriers and enablers as proposed in the two frameworks that guide the research. For Table 6.1, six categories were defined in correspondence with the nuances indicated by participants during the interviews. Participants generally indicated for all contextual factors that either (i) they are generally enabling, (ii) they are enabling for pilots, but barriers might arise in later stages, (iii) they are enabling provided that sufficient proof of financial or sustainable advantages is present, (iv) they are neutral, or the participant did not or could not provide a clear verdict, (v) there are barriers that might affect the process indirectly, or (vi) there are clear and direct barriers. All verdicts by the participants could be put into one of these six categories. This process can be described as a form of grounded theory, where categorization took place based on the results in a bottom-up manner.

Table 6.1. Comparison of participants' views on the contextual conditions.

	A	B	C	D	E	F	G	H	I	J	K	L	M
Policy	Ep	Bi	Bi	N	N	Ep	N	Ep	Ep	Bi	N	N	E
History	N	E	N	B	B	B	B	B	B	Bi	N	B	B
Funding	Ec	B	Ec	Ec	Ec	N	Ec	Ec	Ec	Ec	Ec	Ec	Ec
Infrastructure	N	B	N	E	B	B	B	B	B	Bi	N	B	B
Time	Ec	B	B	Ec	B	N	Ec	E	B	Bi	B	B	B
Geographical proximity	N	N	N	E	E	N	E	N	N	B	N	B	B
Knowledge of each other's pool of resources	E	N	N	N	B	N	B	E	N	B	B	E	B

E	Generally enabling
Ep	Enabling for pilots, barriers might arise in later stages
Ec	Enabling provided there is proof of financial or sustainable advantages
N	Neutral or no clear verdict
Bi	Indirect barriers are present
B	Barriers are clearly present

Table 6.2. Comparison of participants' views on the presence of barriers.

	A	B	C	D	E	F	G	H	I	J	K	L	M
Insufficient finances or financial incentives	Cf	Cf	Cf	Cf	Cf	Cf	Cf	Cf	Cf	Cf	N	Cf	Cf
Lack of techn. knowledge or codification	E	E	E	E	E	E	Ce	E	E	E	Ce	E	Ce
Inadequate provision of information	E	B	B	B	N	N	B	B	B	B	E	E	E
Lack of time to invest in IS engagement	Cf	Cf	B	B	N	N	Cf	Cf	B	B	Cf	Cf	E
Difficulty finding suitable locations	B	Ce	B	Ce	B	B	B	Ce	B	B	B	B	B
Lack of commitment by firm leaders	Cf	Cf	B	B	N	N	Cf	Cf	N	N	N	Cf	N
Lack of public awareness and interest	N	Cs	N	B	Cs	B	N	Cs	Cs	Cs	B	Cs	B
Having a short-term focus	B	B	E	B	B	B	B	N	E	B	N	N	N
Distrust of potential symbiotic partners	E	N	B	Ca	N	B	B	Ca	Ca	B	B	Ca	B
Fear of output quality issues	B	Ca	Ca	Ca	B	B	Ca	Ca	B	Ca	B	Ca	Ca
Fear of not being worth the investment	Cf	Cf	B	B	N	B	Cf	Cf	Cf	B	Cf	Cf	Cf
Lack of public-private cooperation	N	B	Cs	B	N	B	Ce	Cs	Cs	Ce	N	Cs	B

B	Barriers are present
C	Barriers are conditionally present, and can be reduced if
Cf	… there is proof of financial advantages
Cs	… there is proof of sustainability advantages
Ca	… solid agreements are made
Ce	… adequate effort is put into it with existing means
N	Neutral or no clear verdict
E	Barriers are not present

For Table 6.2, four categories were defined in correspondence with the nuances indicated by participants during the interviews, where the second category was additionally divided into four subcategories. Participants generally indicated for all barriers that either (i) they are present, (ii) they are present but can be reduced or removed if certain conditions are met, (iii) the participants were neutral (e.g. they thought the barrier was not relevant) or did not or could not provide a clear verdict, (iv) they are not present. According to the participants' judgment, the conditions relating to the second category were (iia) the presence of proof of financial advantages, (iib) the presence of proof of sustainable advantages, (iic) the presence of solid agreements, or (iid) adequate effort put into the process through existing means and networks (e.g. using existing tools like scans, seminars or workshops). All verdicts by the participants could be put into one of these (sub)categories.

This research aims to represent the barriers to shared refrigeration in Dutch industrial parks accurately. As it turned out that several nuances to the predefined list of barriers were pointed out, the choice has been made to reformulate some of the barriers and enablers in a way that best fits the situation for shared refrigeration in Dutch industrial parks. A synthesis of the newly formulated barriers and enablers can be found in Tables 6.4 and 6.5.

6.1.1 Factors related to policy

6.1.1.1 Contextual conditions

Awareness and interest in industrial symbiosis. Mortensen & Kørnøv (2019) concluded from their literature review that policy changes tend to be important in generating awareness of IS possibilities. Participants indicate that such changes are present due to the **phasing out of synthetic refrigerants** and **increasingly strict sustainability laws**, in combination with the **congestion problems in the electricity network**. The combination of these factors force businesses to find out-of-the-box solutions, which can be favorable for industrial symbiosis emergence.

Nevertheless, several participants indicate that even more incentives could be generated by improving the enforcement of laws and regulations. One participant mentions the possibility of periodical energy performance checks like already present for air conditioning systems. The participant indicates that the lack of enforcement is due to shortages of government personnel.

Reaching out and exploration of connections. Mortensen & Kørnøv (2019) note that successful IS initiation and implementation is often a result of regulatory changes, for which active interaction with public bodies is necessary. The results of this research indicate that there is in fact **active government involvement in sustainable initiatives**. While some participants indicate that there is still a lack of dedicated policy, the government is continuously working on new laws and regulations. Participants indicate that the government will be likely to facilitate pilot initiatives.

Organizing. While the current policy climate is generally deemed by participants to be facilitatory for early stages of the emergence process of shared refrigeration initiatives, and that there are few restrictive laws for sharing industrial refrigeration equipment, participants indicate that there are limitations posed by laws governing heat delivery, which may have effect on the waste heat coupling. Similarly, policy barriers might arise as applications for building permits require standardized (BENG) calculations of energy performance, which is to a high degree determined by the calculation of a CO2 footprint. This footprint is difficult, expensive and time-consuming to establish for nonstandard and tailored applications. The effects these **strict policies for complementary systems** have on the waste heat coupling are likely to have an effect on the whole system, as the waste heat coupling for a large part determines the sustainability performance of the system as a whole. The sustainability performance, in turn, is important for the system to be viable and supported by a wide range of actors.

6.1.1.2 Framework barriers

Participants had mixed opinions about whether there is a **lack of cooperation between the public and private sector**. However, many participants argue that the government is actively engaging in partnerships when it comes to sustainable initiatives, and that there are sufficient forms of collaboration available for public-private partnerships. A lack of cooperation between the public and private sector can thus be considered not to be a significant barrier.

6.1.2 Factors related to history

6.1.2.1 Contextual conditions

Awareness and interest in industrial symbiosis. Mortensen & Kørnøv (2019) concluded from their literature review that the presence of prior collaborations can influence the emergence of new initiatives. The results from this research indicate that these prior collaborations among actors that could participate in shared refrigeration systems are very scarce, so there is generally a **lack of prior experiences**. Some participants state that similar projects may exist, but these are not known to most participants. Prior collaborations between actors in other fields, such as in local business associations, are too basic. The willingness of firms to collaborate in such associations tends to be poor. All in all, there is **incapability of local business associations** to serve as breeding grounds for shared refrigeration initiatives.

However, similar systems to shared refrigeration owned by single companies, as well as from heat or steam initiatives, are more common. As these might have a similar structure in both technology and cooperation process, such projects might serve as examples and sources of experience.

6.1.2.2 Framework barriers

The lack of prior example material, as well as the lack of prior collaborations with parties that would be potential shared refrigeration partners might be a reason for companies to have a **fear of output quality issues** (as there is no prior experience that could demonstrate the system's effectiveness in practice), a **fear of not being worth the investment**, a **lack of commitment by firm leaders** (as there is no prior experience that could demonstrate the system's financial advantages in practice), a **lack of public awareness** and **inadequate provision of information** (as there is no prior experience that could demonstrate the system's safety and sustainability).

6.1.3 Factors related to funding

6.1.3.1 Contextual conditions

Awareness and interest in industrial symbiosis. Mortensen & Kørnøv (2019) concluded from their literature review that financial incentives in the earliest stage of IS emergence usually comes from public bodies, either directly or indirectly. However, eligibility of subsidies might be a problem for shared refrigeration in early stages as participants indicate that most current subsidies are for implementation, rather than for research and investigation. In order to be eligible for subsidies, innovations have to have achieved a certain Technology Readiness Level (TRL). Moreover, businesses too might be reluctant to fund something that has not been adequately researched. Financial assessments will have to be made to establish whether the concept of shared refrigeration will lead to economic gains. This proof will be necessary to evoke the interest and willingness of investors and participants, and will be crucial to the success of shared refrigeration initiatives. Participants generally indicate that economic motivations are the most important reasons for businesses to engage in symbiotic collaborations, which is in line with existing research by Ashton & Bain (2012). If financial assessments of the system will indicate that it is profitable, finding investors will likely not be a major factor. A problem lies mainly in the initial stage of the project's emergence. Making financial assessments requires investigation of suitable locations, as well as an elaborate inventorization of potential partners and their wishes and demands. Such a business case analysis takes time, effort and money to make, while there is no *a priori* proof of the system's profitability. Investors will likely be hesitant to fund such an investigation, and government subsidies are not available if no proof of the system's expected sustainability gain is present. This might result in a **funding gap in the initiation phase**, where there is no party that is willing to kickstart the project.

Organizing. In this phase, funding can increase the success of the establishment of IS, and tends to come mainly from public bodies and business actors (Mortensen & Kørnøv, 2019). Participants generally indicate that funding should not be an issue if there is proof that the project will offer financial and sustainable advantages. There is a **favorable investment climate**, as interest rates are low and there is a general willingness to invest in sustainable technologies. Several natural investment moments are expected to arise between now and 2030, and between 2030 and 2050, due to policy changes.

Nevertheless, the investments required are rather high, and the payback period will likely be long. This might result in **unprofitable front-end investments** (*onrendabele top*), which might pose a threat to the feasibility. Initiatives might have to rely on government subsidies to cover this part of the investment. Participants indicate that there are no dedicated subsidies for refrigeration yet, although subsidies might be found for the waste heat coupling element. In order to receive such subsidies, solid assessments for sustainability improvement have to be presented. Moreover, care has to be taken in that the project's legal structure must allow the project to be eligible for subsidies.

Some participants argue that subsidies need not necessarily be a determining factor as the industry is increasingly finding ways to reduce the unprofitable front-end investments, or to cover these themselves.

6.1.3.2 Barriers

Participants indicated that insufficient finances or financial incentives would not be a barrier provided there is clear evidence that a shared refrigeration system will have financial and sustainable advantages, so that it can be argued that this comes forth from a **lack of financial and sustainable assessments**. However, participants indicate that potential partners tend to **have a short-term focus**, which in combination with the long payback period which shared refrigeration investments will probably have may lead to unwillingness to invest. Moreover, there may be a **fear of not being worth the investment** that will not entirely be taken away by solid financial assessments, as there will always be a risk of partners prematurely ending their participation in the shared refrigeration network, which can weaken the business case and jeopardize profitability.

6.1.4 Factors related to infrastructure

6.1.4.1 Contextual conditions

Reaching out and exploration of connections. Mortensen & Kørnøv (2019) concluded from their literature review that knowledge sharing databases, interaction platforms and similar structures for actor interaction are critical in this phase. Participants indicated that several of such interaction structures exist or are in the process of being created, like regular seminars and workshops, national action plans, and databases of information and scans (like the *Warmteatlas*). There is **active knowledge sharing by governments and consultancy firms**, including face-to-face meetings, which are important to build trust.

However, these somewhat broad platforms are not always joined by a tailor-made selection of participants that have the potential to specifically collaborate with each other. On the contrary, some interaction events might be attended by competitors who have a **fear of competitive threats** by sharing too much information. Local associations are more suitable platforms, but these are usually poorly organized and do not have the qualities to be a suitable interaction platform, if they are present in the first place. Again, it can be argued that there is **incapability of local business associations**. Therefore, dedicated platforms will have to be developed specifically for each project. One participant argues that the formation of these collaborations depends on the degree of urgency. He argues there is currently **low urgency to explore shared refrigeration**.

Organizing. Mortensen & Kørnøv (2019) argue that databases and other overviews are important in this phase. Similar to what has been mentioned above, there seems to be a **lack of dedicated scans and databases**, which will have to be developed specifically for each project.

6.1.4.2 Barriers

Participants had mixed opinions about whether **inadequate provision of information** about concepts like shared refrigeration is a barrier. A general tendency in the results seems to be that the channels for information dissemination are available, but that these need improvement. Information is generally disseminated top-down, by the government, consultancy firms and academia, but horizontally there is still a **lack of knowledge sharing among businesses**. There is general consensus among participants that there is no **lack of technological knowledge or codification**, although several participants argue that the knowledge is scattered and needs to be assimilated. Participants indicate that although there would be knowledge to realize a shared refrigeration system, this knowledge is held by only a small part of businesses. There is **suboptimal exploitation of available technological knowledge**.

6.1.5 Factors related to time

6.1.5.1 Contextual conditions

Reaching out and exploration of connections. Mortensen & Kørnøv (2019) concluded from their literature review that the emergence process of industrial symbiosis requires time for trust building and the establishment of connections. The results of the current research indicate that for shared refrigeration, not only the availability of time after a project´s initiation is important, but also the alignment of timelines of different actors and events for windows of opportunity to emerge.

Participants indicate that a feasibility study for a project like this could start at any time, and timing of the start is not the determining factor. After the initiation however, the alignment of natural investment moments is a challenge, as these are different per company. There is often a difference between the heating and cooling demand within an industrial park, so the initiative would probably only be viable if coupled to a heating grid in a residential area that is newly built, or already exists but is ready for an energy transition. These situations will not always be present at the right time, leading to a **scarce occurrence of opportunity windows**.

The misalignment of opportunity moments may result in a situation where it is inevitable that a shared refrigeration system is laid out in advance, with only a few users connected to it from the start, after which other users arrive at the location later on. Such a situation will result in higher **unprofitable front-end investments**. It will pose challenges to the research and investigation stage as well, as calculating the advantages of a shared refrigeration system requires mapping the demand profiles of the participants, which more or less turns into a guess if the participants have not yet been identified. Whether estimations of the demand prospects are reliable enough will depend on each specific context.

Finally, the **long investment horizon** of the project will require patience and commitment from participants. There might be a reluctance by businesses to commit themselves for such a long period as their investment horizon is usually shorter (many participants indicate that this is due to SMEs **having a short-term focus**), and they face the risk of economic decline during the investment payback period. Also, the patience of participants will depend on the advantages shared refrigeration will have to offer. As of now, these advantages are not clear due to a **lack of financial and sustainable assessments**.

6.1.5.2 Barriers

There is general consensus among participants that there is usually a **lack of time to invest in sustainable collaborations** among SMEs, although some stress that this lack of time depends on the level of expected profitability of the system, or the level of urgency there is to engage in such a collaboration (due to e.g. stricter environmental policies or network congestion). The same applies for a **lack of commitment by firm leaders**. Participants indicate that businesses will want to participate if it leads to financial gains, but will not want to invest themselves in the development process. More suitably, the current underlying barriers could be argued to be a **lack of financial and sustainable assessments** and **lack of urgency to explore shared refrigeration**.

6.1.6 Factors relating to geographical proximity

6.1.6.1 Contextual conditions

Reaching out and exploration of connections. Mortensen & Kørnøv (2019) concluded from their literature review that there is no agreement among researchers what the role of geographical proximity on the success of IS emergence is. For shared refrigeration, it has become obvious that the distance between partner businesses attached to the network is crucial for the network's performance - the smaller this distance, the better. Participants argue that there are clusters of businesses with a similar refrigeration demand in the Netherlands, although most businesses are likely scattered all over the country. Moving businesses to a new location for the sole purpose of taking part in a shared refrigeration network is difficult, especially because of the nature of agrofood firms. The combination of these factors is an important constraint for the concept of shared refrigeration, as it leads to an increased **difficulty finding suitable locations for implementation**.

In terms of connecting and exploring connections, permanent geographical proximity is not an absolute necessity, as some participants recall from experience that temporary geographical proximity, for example by bringing firm leaders together for conferences or workshops, has also been effective in establishing ties. Conversely, one participant mentions that such interactions do not always result in positive outcomes, as distrust might also develop.

6.1.6.2 Barriers

All participants indicate that **difficulty finding suitable locations for implementation** will be an important barrier, mainly because the successfulness of shared refrigeration systems depends on so many different elements. Three participants indicate that adequate opportunity scanning can be a solution for this difficulty. However, one participant mentions from experience that even when suitable locations are found, the process of launching sustainable collaborations is difficult.

6.1.7 Factors relating to knowledge of each other's resources

6.1.7.1 Contextual conditions

Reaching out and exploration of connections. Mortensen & Kørnøv (2019) concluded from their literature review that knowing what other parties are doing, what they need and what they have to offer is important for successful emergence of IS. Although several participants state knowledge exchange between parties is happening regularly, many participants argue that the situation is still suboptimal. A red line through the results is that information sharing tends to be organized mostly in a vertical, top-down manner. Participants indicate that there is still a **lack of knowledge sharing among businesses** in a horizontal manner, confirming the findings of Madsen et al. (2015) quoted by Mortensen & Kørnøv (2019), who state that neighbors do not know of each other what they are doing, resulting in a lack of outreach among them. Participants indicate that although there may be distrust to share information, the actual data that will need to be shared for shared refrigeration is not sensitive to competitive threats.

6.1.7.2 Barriers

Similar to what was mentioned in Section 6.1.4, there might be **inadequate provision of information** about sustainable refrigeration among suppliers and consumers. Participants attribute this partly to a "partial" **lack of technological knowledge or codification**, in the sense that knowledge about sustainable refrigeration and novel technologies is held by only a part of suppliers and installation companies. Consumers, who generally have less knowledge of refrigeration technology, depend on the expertise of installation companies to provide them with sustainable equipment and support them in engaging in sustainable collaborations with others. However, participants indicate that many installation companies tend to stick to more traditional technology and tend to be lagging behind a bit with the implementation of innovative solutions. They attribute this partly to a lack of knowledge and personnel among installation companies. Overall, there can be said to be **suboptimal exploitation of available technological knowledge**.

Another factor that tends to inhibit knowledge sharing among consumers is that they tend to have a **distrust of potential symbiotic partners**. As explained in previous chapters, the successfulness of shared refrigeration systems will for an important part depend on the extent to which participants have a demand for similar temperature levels. Requiring the same temperature levels implies similarity in business operations, which means that companies with a similar temperature demand have a larger probability to be competitors. The paradox is therefore that the more promising a situation is for a shared refrigeration system, the more distrust there will be among potential partners, and thus it will be more difficult to establish collaborations.

6.1.8 Actors and actor roles

In order to compare the results with the framework, a classification was made of the participants' views about actors and their roles in different stages of the IS emergence process. This classification can be found in Table 6.3.

Table 6.3. Comparison of participants' views on actor involvement with the model of Mortensen & Kørnøv (2019).

	Advisory	Champion	Facilitatory	Coordinating	Funding	Following suit
Research and education institutions	AJ					
Consultancy companies		ABCDHIJ				
Governments	EF	EF	EFGH	ABDEFGM	EFHIJM	
Businesses		GJ, LM*, EK**	LM*	LM*	EGJM	DEHIJL
Associations	ADH	E***	ADH	ADH		

Remarks

* These participants envision a role as anchor tenant for a "dominant partner"
** These participants think there will be few businesses willing to be champions
*** This participant believes only a public-private partnership can take the lead

Legend of phases

1. Awareness & interest in IS
2. Reaching out & exploration of connections
3. Organizing

1 and 2

2 and 3

1, 2 and 3

In this table, a letter indicates that the participant corresponding to that letter mentioned that he thinks the actor in the respective row will take the role in the respective column during the emergence process of shared refrigeration initiatives. A colored cell background indicates that Mortensen & Kørnøv (2019) mention these roles for the respective participants in their model. Color codes are used to distinguish between the different phases described in their framework.

Many participants expressed views about actor involvement that were in line with the findings of Mortensen & Kørnøv (2019). However, there are several points of interest where the participants had views that differed from the model.

6.1.8.1 Consultancy companies

Consultancy companies are seen by many participants as missionaries, taking the initiative in early stages of the process. However, in the theoretical framework they are described to play a more passive, rather advisory role, and their participation starts only in later stages of the process.

6.1.8.2 Businesses

Businesses are expected by some participants to be mostly passive players in the process, following suit due to a lack of interest to take the lead. According to the framework of Mortensen & Kørnøv (2019) however, it is important for them to play a more active role in the process to ensure success of the initiative. Nevertheless, some participants, notably including participants from the business stakeholder group, indicate that they do see an important role for businesses as anchor tenants. This is in line with the model of Mortensen & Kørnøv (2019).

6.1.8.3 Research and education institutions

Lastly, research and education institutions are not mentioned to play a role by many participants. However, the model of Mortensen & Kørnøv (2019) indicates that in situations where IS emergence was successful, research and education institutions do play a role, especially in the first stage as champion, facilitator and coordinator.

6.1.9 Actor characteristics

Several results indicate that especially businesses tend to have characteristics that do not entirely align with those that are facilitatory to the emergence of IS initiatives described by Mortensen & Kørnøv (2019). Discrepancies between the success factors and the results of this research will be discussed below, where words highlighted in bold indicate factors that Mortensen & Kørnøv (2019) argue are crucial for the success of IS emergence.

Whereas participants from the business stakeholder group indicated that they did have an **environmental mindset and awareness**, nearly all of them nuanced their statements by saying that the actual application of sustainable practices in their company was too limited, that they would like to increase their company's sustainability but did not have the capacity to spend time and resources for it, that their sustainability-increasing efforts were due to government regulations, or that they would not have done certain sustainable investments if those would not have led to economic gains. Other participants indicated that they felt businesses have insufficient awareness of sustainable alternatives to their current means of operation.

As mentioned in several previous sections, **knowledge sharing** and **openness** among businesses is suboptimal for various reasons. Participants indicate that the extent to which businesses are willing to share knowledge depends on the type of company (participants state that younger, innovative companies are willing to collaborate more, and that family businesses tend to be more involved with their environment and willing to engage in longer-term initiatives. The statements about family businesses are in line with prior research by Klewitz et al. (2012) and Sharma (2004)), and on the type of information being shared. Participants do indicate that although businesses tend to be afraid of losing their competitive advantage, refrigeration demands would not be considered sensitive data.

Mortensen & Kørnøv (2019) conclude that it is important for actors to have a **proactive attitude** in the IS emergence process. However, participants indicate that many businesses will not have a particularly proactive attitude. Shortage of personnel and economic considerations are mentioned as reasons for companies to want to stick to their core business, of which refrigeration is usually not a part. They would therefore not want to be actively involved in the development process. However, one participant indicated that their company does in fact have a proactive attitude towards such collaborations. It is worth noting that this particular company has a rather large refrigeration demand, which places refrigeration closer to its core business. It can be argued that a proactive attitude will be held by businesses for which refrigeration is a crucial aspect of their operations, and that other businesses will have a more reactive attitude. This is in line with findings of the preparatory round of interviews. It is further worth noting that the participant who mentioned having a proactive attitude suggested that he would be interested in taking the role of anchor tenant.

Also, results indicate that businesses tend to not be very involved in their local business associations. This means their **social proximity** is not optimal, and they are less likely to **build and mobilize relational capacity** among potential symbiotic partners.

Governments generally have characteristics that are in line with those that are facilitatory to the emergence of IS initiatives described by Mortensen & Kørnøv (2019). However, one participant mentions that he perceives the government als unreliable and unstable. This implies that the government is underperforming in **cultivating trust**, which is a critical factor in the initial stage of IS emergence according to Mortensen & Kørnøv (2019).

Characteristics of research and education institutions and business associations are difficult to describe as the results of this study do not include sufficient data regarding those characteristics. However, as research and education institutions tend to have a very wide range of characteristics that are generally very facilitative for sustainable initiatives, their characteristics can likely be regarded as enabling. Business associations are very diverse in nature and have different characteristics, but the results indicate that local business associations, which have the potential to be the most relevant breeding ground for symbiotic initiatives, generally have very poor characteristics with regards to fulfilling that role. Only after these associations have been adequately set up and empowered, an analysis of their characteristics will be of relevance.

6.1.10 Actor activities

The results of this study indicate that governments, research and education institutions consultancy companies are already actively engaging in activities that have proven to be successful for IS emergence in the past according to the review of Mortensen & Kørnøv (2019). This includes the **formation of networks of potential stakeholders, communicating the value of IS, ensuring a**

continuous dialogue, acquisition of knowledge and relationships, formation of mobilization capacity, periodical meetings, on-site guidance, face-to-face discussions and **networking events and workshops**. Per definition, all these activities also involve businesses. While, the results of this research do not indicate that businesses themselves take a leading role in these activities, this does not mean that the situation is bad. It can be argued that in these processes, businesses simply do not act as coordinators of facilitators. These are roles that, according to the model of Mortensen & Kørnøv (2019), need not be fulfilled by businesses, but can be fulfilled by other stakeholders.

The finding that the activities mentioned above are taking place in the context of industrial symbiosis facilitation, implies that these activities could probably also be mobilized to benefit shared refrigeration initiatives.

6.1.11 Synthesis of barriers and enablers

A summary of the barriers and enablers that have been identified from the results of the stakeholder interviews can be found in Tables 6.4 and 6.5. As some barriers were deemed to be interrelated or dependent on certain conditions, proposed umbrella barriers and umbrella enablers are suggested to attempt to capture the essence of those barriers. These umbrella factors were conceived based on the findings of this research and the insights gained about the nuances related to the original factors as indicated by the participants. Both the original factors and the umbrella factors are useful to gain understanding of the situation. However, the use of umbrella factors aims to prevent redundancy and to cover interrelatedness between some factors. Therefore, the umbrella factors will be used as a reference in further sections of this report.

Table 6.4. Enablers for shared refrigeration in Dutch industrial parks.

<table>
<tr><th>Enabler</th><th>Umbrella enabler</th></tr>
<tr><td>Phasing out of synthetic refrigerants</td><td rowspan="3">Favorable policy climate</td></tr>
<tr><td>Increasingly strict sustainability laws</td></tr>
<tr><td>Active government involvement in sustainable initiatives</td></tr>
<tr><td>Congestion problems in the electricity network</td><td>Congestion problems in the electricity network</td></tr>
<tr><td>Favorable investment climate</td><td>Favorable investment climate</td></tr>
<tr><td>Active knowledge sharing by governments and consultancy firms</td><td>Active knowledge sharing by governments and consultancy firms</td></tr>
</table>

Table 6.5. Barriers to shared refrigeration in Dutch industrial parks.

Barrier	**Umbrella barrier**
Funding gap in the initiation phase	Funding gap in the initiation phase
Unprofitable front-end investments	Long investment horizon
Long investment horizon	
Fear of not being worth the investment	
Having a short-term focus	
Lack of financial and sustainable assessments	Lack of urgency to explore shared refrigeration
Lack of commitment by firm leaders	
Lack of urgency to explore shared refrigeration	
Lack of prior experiences	Lack of prior experiences
Incapability of local business associations	Incapability of local business associations
Lack of knowledge sharing among businesses	Inadequate information sharing
Inadequate provision of information	
Lack of dedicated scans and databases	
Suboptimal exploitation of available technological knowledge	
Lack of public awareness	
Fear of output quality issues	Fear of losing control and independence
Distrust of potential symbiotic partners	
Fear of competitive threats	
Difficulty finding suitable locations for implementation	Scarcity of implementation opportunities
Scarce occurrence of opportunity windows	
Strict policies for complementary systems	Strict policies for complementary systems

6.2 Facilitating the emergence of shared refrigeration

This section will discuss ways to overcome the barriers that have become apparent from the previous section. It will do so by synthesizing facilitatory measures proposed by the participants of the current research and findings of earlier research.

6.2.1 Overcoming the barriers

6.2.1.1 Funding gap in the initiation phase

Literature has shown that in successful IS initiatives, financial support and incentives mostly came from public bodies (Elabras Veiga & Magrini, 2009; Wu et al., 2016; Park et al., 2016; Mortensen & Kørnøv, 2019), indicating that governments are the ones to kickstart early research. As dedicated subsidies for refrigeration do not yet exist, the government could explore possibilities to create these.

6.2.1.2 Long investment horizon

Participants generally indicate that economic motivations are the most important reasons for businesses to engage in symbiotic collaborations, which is in line with existing research by Ashton & Bain (2012). Unprofitable front-end investments can be a jeopardizing factor to the profitability of a shared refrigeration business case, and care must be taken to back up these costs using subsidies or other types of financial support mechanisms. Again, literature has shown that in successful IS initiatives, financial support and incentives mostly came from public bodies (Elabras Veiga & Magrini, 2009; Wu et al., 2016; Park et al., 2016; Mortensen & Kørnøv, 2019), indicating that subsidies might be a successful instrument for this purpose.

6.2.1.3 Lack of urgency to explore shared refrigeration

There is a need for proper assessments of financial and sustainable implications of shared refrigeration in order to ensure the willingness of potential partners to commit themselves to the project. The results of this research indicate that businesses do not have sufficient capacity, including personnel and resources, and/or do not see enough urgency, to invest in sustainable collaborations like shared refrigeration. Presenting them with reliable predictions of financial and sustainable benefits of shared refrigeration may increase their willingness to commit themselves to the project.

Participants also indicate that extrinsic measures like stricter government regulations have turned out to be a reason why businesses decide to make sustainable investments. More policy incentives can be created to increase the industry’s readiness to invest in sustainable refrigeration. This includes improving the enforcement of current measures. Some researchers have argued that it is more useful to put emphasis on overcoming external policy and financial barriers than internal barriers relating to technology and management (Sizhen et al., 2005; Sillanpää and Ncibi, 2019). Fernández-Viñé et al. (2013) among many argue that governments may employ many instruments to foster the engagement of SMEs in sustainable initiatives. It is essential to conceive a coherent strategic roadmap to prevent contradictory incentives and mismatches (De Jesus and Mendonça, 2018).

Lybaek et al. (2021) noted that policy and regulations that do not specifically focus on the implementation of IS were often important drivers for IS realization. This sounds paradoxical, but the importance of this indirect enabling was already stressed by Desrocher (2004) and Desrochers and Sautet (2008), who argued that policies that are bottom-up oriented and enable entrepreneurial behavior are better than policies that are prescriptive and top-down in nature. Needless to say, many ways to create such a policy are possible. For example, Prieto-Sandoval et al. (2018) note that certification with "eco-labels" and environmental management standards are often useful to facilitate implementation of circularity. The positive effects of certification are also demonstrated by Daddi et al. (2016), who base this on Italian real-world examples. Taddeo et al. (2017a) suggest that "innovation poles", government-funded consortia that promote innovation, might be a good instrument to promote the development and implementation of IS. Millette et al. (2020) propose a framework for incubators that could foster initiatives relating to the circular economy. Such incubators could, depending on the specific context, be coordinated by governments or universities.

6.2.1.4 Lack of prior experiences

The results of this research indicate that the lack of prior collaborations and practical implementations of the system could be a cause for much uncertainty, unawareness and perhaps even resistance among potential partners and the general public. Research has already shown that prior experiences are crucial for the emergence of new symbiotic collaborations (Ashton, 2009; Van Berkel et al., 2009; Behera et al., 2012; Paquin et al., 2014; Farel et al., 2016; Branson, 2016), but it has also been concluded that there have been little experiences concerning SMEs engaging in industrial symbiosis (Ruiz Puente et al., 2015). The results of this study are in line with these findings. A review by Eilering and Vermeulen (2004) of early implementations of IS in the Netherlands, showed that in all cases of successful IS partnerships, the companies already knew each other, sometimes even having been business partners for a long time. The results of the current study indicate that this situation does not apply to potential partners of Dutch shared refrigeration networks. It will therefore be important to provide other means to build trust between stakeholders, and to provide proof of the system's advantages to potential partners and the general public. This includes providing solid theoretical and/or experimental assessments of the financial and sustainable benefits of shared refrigeration systems, as well as any health or safety risks that the system might pose to its environment. If any shared refrigeration projects are implemented, experiences should be disseminated adequately. Moreover, participants indicate that elements of existing projects that are similar in nature and structure, like large refrigeration networks with a central refrigeration facility operated by a single company like an auction building, may be used to provide examples. Veleva et al. (2015) note, building on Tudor et al. (2007), that constant communication towards local organizations about available sustainability programs is very important in increasing collaborations and reaching sustainability goals. Borsacchi and Pinelli (2020) suggest storytelling about circular products and services to make customers and other businesses aware of their benefits. In the same spirit, Herczeg et al. (2018) argue that businesses already working together in a symbiotic relationship should engage in collective learning about each other's needs to help them solve strategic problems.

Patricio et al. (2018) and Neves et al. (2020) propose that some barriers for IS can be overcome by disseminating experiences and best practices of successful IS networks, and allowing successful models to be copied. Patricio et al. (2018) suggest that not only qualitative information be shared, but also quantitative data concerning e.g. costs and profits, to help SMEs understand the benefits of symbiotic partnerships better. However, they do not mention how this can be done best, and recommend further research on how industrial associations, governments, and regional developers can facilitate the promotion of IS among SMEs.

On a cautious note, Chertow (2000) notes that explaining and promoting IS to a large crowd requires relatively large transaction costs for as long as many parties are still not aware of it. This is a point that should be kept in mind.

6.2.1.5 Incapability of local business associations

The results of this research indicate that although infrastructure for top-down information sharing is present, dedicated platforms for interaction between potential shared refrigeration partners are lacking. Information flows are therefore not optimal and should be improved, most importantly by establishing and/or improving the performance and capabilities of local business associations. These local business associations can boost not only shared refrigeration initiatives, but also other kinds of sustainable collaborations (cf. Ormazabal et al., 2018). However, participants indicated that these local associations currently often do not have the capacities to play this role. Local business associations need to be set up and/or empowered so that they have the capacity to be a fertile breeding ground for symbiotic collaborations. In order to do this, businesses need to be convinced of the value of joining such a local association, and they need to be provided with sufficient knowledge and innovative capacity.

Participants indicate that it might be beneficial for the emergence of sustainable collaborations to include other actors in local business associations as well, like governments (to provide stability and guidance) and consultancy firms or installation companies (to provide knowledge and expertise). Prior research has confirmed that such collaborations are beneficial to eco-innovation (Jenkins, 2009; LePoutre and Heene, 2006; Valliere, 2006; Klewitz et al., 2012) and engagement of SMEs in industrial symbiosis (Susur et al., 2019). Local champions are especially important as they have a crucial role in instigating the formation of networks (Susur et al., 2019; Chertow, 2008; Roberts, 2004; Heeres et al., 2004).

Although consultancy firms are among the parties that put most effort into capacity building activities, them playing the role of champion, facilitator or coordinator in IS emergence processes is not recognized as being critical for success in the framework of Mortensen & Kørnøv (2019). The researchers mention that usually, other actors act as champions, notably businesses, governments and business associations. Opportunities might lie in partnering up consultancy firms and these actors in order to come to a combined powerful position. An especially interesting opportunity might lie in partnerships with larger businesses to which refrigeration is a key element of their operations. These businesses, who may take the role of anchor tenant, will be more likely to have a proactive attitude and be willing to invest effort in concepts like shared refrigeration, as it might lead to significant benefits for them.

While the results indicate that governments and consultancy firms especially have been putting active effort in capacity building activities, the role of research and education institutions in those activities is poorly recognized by the participants of the interviews. Their role might have to be either increased or made more apparent. Although a participant from the research and education stakeholder group argues that shared refrigeration is not a high-tech subject and therefore does not have the focus of research and education institutions, he and other participants mention that students might serve as bridging actors between research and education institutions and other stakeholder groups. Internships, student jobs, or educational projects in collaboration with the industry or consultancy companies might be a suitable tool for increasing student engagement. This may have extra benefits in the sense that the world of refrigeration is brought to the attention of more students, which might lead to more interest among jobseekers.

It has been argued in prior research that SMEs tend to have suboptimal networking skills (Bigliardi et al., 2011). Therefore, it has been argued that public bodies are the ones to take the lead in fostering network formation (Vermeulen, 2006). Susur et al. (2019) also propose a top-down approach building a social network for potential IS participants, as well as a base of expectations and motivation. Local business associations can act as platforms for such networks and thus form good focal elements for governments. Public bodies can be directed to help local business associations build up the necessary network, capacities and resources. Costa and Ferrão (2010) argue that spontaneous emergence of IS collaborations is not uncommon, but that a context that enables the collaborations to emerge is necessary. The government could coordinate such a process (Costa and Ferrão, 2010; Cervo et al., 2019).

Heeres et al. (2004) note that there might be cultural factors affecting the effectiveness of policy instruments, because the attitude of businesses towards the government differ per region. Therefore, governments should carefully review their approach in attempting to create IS networks. Moreover, the results of this research indicate that rapid changes in regulations might lead to a distrust towards the government. This is in line with previous research by Eilering and Vermeulen (2004), who show that government involvement can stimulate the formation of IS networks and take the initiative, but note that governments should seriously avoid planning IS networks without involving the businesses and other stakeholders as that might result in no support from those parties. Support of the private sector is of the utmost importance in creating IS (Chertow, 2000). Multiple studies are in line with this warning, indicating that a bottom-up approach to stimulate IS is more effective than top-down approaches (Desrochers, 2004; Desrochers & Sautet, 2008; Taddeo et al., 2017b; Lybaek et al., 2021).

6.2.1.6 Inadequate information sharing

The results indicate that although efforts are made to increase knowledge sharing among businesses, there is still poor horizontal knowledge sharing among businesses. This horizontal knowledge sharing is crucial for the successfulness of IS initiatives (Cutaia et al., 2015). Research has shown that firms perform better at innovation if they engage in collaboration with other partners, potentially even with competitors (Zeng et al., 2010; Schøtt & Sedaghat, 2014).

The main factors to which the lack of horizontal information sharing is attributed by participants are a lack of innovative solutions offered by installation companies, and a lack of collaboration between consumers, for which distrust is an important reason. Moreover, consumers might have a fear of output quality issues of their production when being dependent on other parties in a shared refrigeration system. Participants suggest that the distrust can be taken away by creating solid agreements between consumers. Yeo et al. (2019) and Rincón-Moreno et al. (2020) suggest that IT tools might relieve some of the concerns companies have about output quality and reliability of partners by providing transparency and traceability of process streams. Yazan et al. (2020) suggest that online platforms might facilitate negotiation processes concerning the economic terms of IS relationships, preventing opportunism and promoting fair play. Earlier research by Albino et al. (2016) proposed contractual mechanisms to foster the emergence of symbiotic relationships.

Participants indicate that consumers tend to prefer focusing on their core business and having installation companies take care of the refrigeration equipment for them. Therefore, installation companies can play an important part in offering collaborative solutions to their customers, persuading them to reach out to their neighbors, and facilitating the creation of agreements between businesses. Participants argue that consumers will likely not initiate collaborative agreements themselves. Nevertheless, installation companies like many businesses tend to struggle with a shortage of personnel, which is a major obstacle for them to occupy themselves with offering innovative solutions. Indeed, recent data presented by the Dutch government indicates that the shortage of personnel is an important barrier to the sustainable energy transition (Rijksoverheid, 2021; NOS, 2021). Prior research has indicated that a shortage of personnel is in fact a long-standing barrier to the engagement of SMEs in sustainable innovation (Jenkins, 2004; Spence, 1999). Participants from the installation sector indicate that there is insufficient capacity to get the knowledge level within the organizations up to par. So, in order to facilitate the emergence of more symbiotic collaborations between end users, a good first step will be to attract more adequately trained technical personnel. Increasing the knowledge base in a company improves that company's absorptive capacity (Cohen and Levinthal, 1990), implying that the more knowledge a firm has, the more successful it will be in assimilating newly acquired knowledge (Ar and Baki, 2011; Jantunen, 2005; Zahra and George, 2002).

6.2.1.7 Fear of losing control and independence

As stated before, participants suggest that fears relating to competitive threats and output quality, as well as distrust of potential symbiotic partners can be taken away by creating solid agreements between consumers. Yeo et al. (2019) and Rincón-Moreno et al. (2020) suggest that IT tools might relieve some of the concerns companies have about output quality and reliability of partners by providing transparency and traceability of process streams. Yazan et al. (2020) suggest that online platforms might facilitate negotiation processes concerning the economic terms of IS relationships, preventing opportunism and promoting fair play. Earlier research by Albino et al. (2016) proposed contractual mechanisms to foster the emergence of symbiotic relationships. Participants of the current research also indicate that the collaboration terms need to be made very clear in an early stage to prevent distrust and a fear of losing competitive advantage.

6.2.1.8 Scarcity of implementation opportunities

The results of this study indicate that finding locations for implementation will be a challenge because of the many elements that need to be present for shared refrigeration, including clustering of businesses with similar refrigeration demands and opportunities for waste heat reusal. However, finding these locations will likely not be impossible. Windows of opportunity will be scarce, and patience and commitment of participants is of great importance. This is in line with the findings of Mortensen & Kørnøv (2019). Scans will need to be made to identify windows of opportunity, and if such a window is expected to arise, there is a need for a party to take the lead and initiate a business case analysis. According to the review by Mortensen & Kørnøv (2019), this task can be fulfilled by several actors, such as research and education institutions, governments, associations and businesses, especially anchor tenants.

Dias et al. (2020) propose a general framework with guidelines and a technical viability analysis to assist the identification of potential synergistic relationships. Similarly, Pigosso et al. (2018) discuss a screening tool that can help SMEs discover potential symbiotic relationships, and argue that such a tool can help increase long-term success. King et al. (2020) and Lybaek et al. (2021) indicate that giving businesses access to "matchmaking" platforms can increase the awareness about potential IS partners, and facilitate their mutual introduction. Such matchmaking platforms can create and strengthen interfirm alliances, which are beneficial for IS engagement and the creation of EIPs (Chen, Zhou, Zhou & Xue, 2017; Chen, Xu & Zhou, 2017). Tödtling & Kaufmann (2001) argue that regional innovation networks have an enabling effect on the engagement of SMEs in sustainable initiatives. Several participants in this study confirm this from experience.

6.2.1.9 Strict policies for complementary systems

The results of this research indicate that the policy climate is generally considered to be favorable for sustainable collaborations. However, there is insufficient proof that the concept of shared refrigeration will lead to sustainability gains. This proof will be necessary to evoke the interest and willingness of governments to support shared refrigeration projects. Participants argue that if proof of sustainability is provided, the government will likely be willing to support shared refrigeration projects, especially in the pilot stage. However, they argue that establishing this proof might turn out to be complex due to the nonstandard nature of the project and the many different elements that constitute it. Officially recognized calculations will likely be expensive and time-consuming to make. Moreover, while a waste heat coupling is an essential part of the system in terms of sustainability gains, heat applications for the built environment are subject to legislation that can be demanding, complicated and time-consuming to comply with. This might increase costs, reduce profitability, and deter investors to invest in shared refrigeration systems, as well as exploitants from taking the responsibility of exploiting the systems on them. Policymakers might consider revising the legislation surrounding the required energy calculations to facilitate the legal acceptance of more sustainable but less standard applications, for example by recognizing more calculation tools and keeping an open mind for new possibilities.

6.2.2 Strategic roadmap

Using the findings of this research, a conceptual strategic roadmap can be constructed to serve as a useful tool for all stakeholder groups to assess what they can do to facilitate the emergence of shared refrigeration. In Table 6.6, a summary is presented of barriers (the umbrella barriers from Section 6.1) and potential overcoming strategies (as explained in Section 6.2.1) structured according to the phases from the framework of Mortensen & Kørnøv (2019). The rightmost column indicates which actor might take on the task of executing the strategy, based on Section 6.2.1.

This roadmap will be useful for actors from all stakeholder groups to help them strategize how to best approach engagement of their organization in shared refrigeration initiatives, and how to further advance the technology and increase adoption rates over the whole industry.

Table 6.6. Facilitating shared refrigeration in Dutch industrial parks *(continued on next page)*.

Phase	Associated barriers	Potential solutions	Potential actors
Awareness and interest in IS	Lack of prior experiences	Presenting potential partners with trustable analyses of expected advantages of shared refrigeration, and results and experiences from similarly structured projects that have been implemented. Ensure active communication about available sustainability programs.	Any
	Incapability of local business associations	Improving the performance and capabilities of local business associations. For example by creating partnerships between consultancy firms, local champions, and governments or other associations. Public bodies should take the lead in network formation, but ensure that businesses are given an important role in the process as well (combination of top-down and bottom-up approach).	Public bodies
		Involve students in the project through internships, student jobs or other forms of collaboration with research and education institutions.	Research and education institutions
	Lack of urgency to explore shared refrigeration	Presenting potential partners with trustable analyses of expected advantages of shared refrigeration.	Any
		Enforcing current legislation better and creating more policy incentives to engage in sustainable collaborations, while using a clear strategic roadmap and ensuring constant communication across stakeholders.	Public bodies
	Fear of losing control and independence	Ensuring that interactions and agreements are structured according to solid agreements and contracts. Collaboration terms need to be made very clear in an early stage.	Public bodies, business associations
	Funding gap in the initiation phase	Creation of dedicated subsidies by public bodies, or a form of private subsidization, to assess financial and sustainable implications of shared refrigeration systems.	Public bodies, private investors

Table 6.6. Facilitating shared refrigeration in Dutch industrial parks *(continued)*.

Phase	**Associated barriers**	**Potential solutions**	**Potential actors**
Reaching out and exploration of connections	Lack of urgency to explore shared refrigeration	Establish dedicated "innovation poles", consortia that serve as promoters and incubators of shared refrigeration.	Any
	Scarcity of implementation opportunities	Establishing dedicated and effective scanning tools, like a screening tool or matchmaking platform, to identify windows of opportunity. Ensuring that should such a window occur, there is a party that will initiate a business case analysis.	Public bodies, research and education institutions
	Inadequate knowledge sharing	Attract more adequately trained technical personnel to installation companies, to increase their knowledge base and absorptive capacity. Installation companies can then improve their exploration and their offering of sustainable, integrated solutions including shared refrigerations.	Businesses, public bodies, research and education institutions
Organizing	Strict policy for complementary systems	Revising legislation surrounding shared refrigeration (for example the required energetic calculations) to facilitate the legal acceptance of more sustainable but less standard applications.	Public bodies
	Long investment horizon	Presenting potential partners with trustable analyses of expected advantages of shared refrigeration.	Any
		Creating financial backup structures to cover unprofitable front-end investments, for example by providing government subsidies.	Public bodies, private investors
	Inadequate information sharing	Ensuring that interactions and agreements are structured according to solid agreements and contracts. Collaboration terms need to be made very clear in an early stage.	Business associations, public bodies

6.3 Insights from other scientific areas

Findings from other (related) scientific areas can be useful to derive additional recommendations for facilitating successful emergence of shared refrigeration technology. This section will discuss shared refrigeration in the light of the scientific areas of policy mixes, adoption and diffusion, sustainable transitions, and design dominance.

6.3.1 Policy mixes

It can be seen in the previous section and Table 6.6 that public bodies have an important role in executing many of the facilitation strategies. As policy-making is a crucial element that can "make or break" successful implementations of shared refrigeration, care should be taken in deciding which policy instruments and which implementation strategies are to be employed. It is likely that several different elements and strategies will be necessary to successfully facilitate shared refrigeration, which would be implemented in addition to already existing policies and governance processes. The resulting combination of policy elements and strategies, also referred to in literature as a *policy mix*, is what will be driving the technological change necessary for shared refrigeration.

6.3.1.1 Relevance of the policy mix concept

Policy mixes consist of three building blocks: *elements, policy processes*, and *characteristics* (Rogge & Reichardt, 2016). Moreover, they can act in multiple *dimensions.* A graphical representation of these building blocks can be seen in Figure 6.1. The framework by Rogge & Reichardt (2016) shows that there are many more factors to take into account than only instruments and implementation strategies. Public bodies should carefully assess what prospected effects the envisioned policy mix will have on shared refrigeration, also taking into account underlying processes that have led to the creation of the new policies as well as the dimensions in which the mix will act. Assessing the characteristics of the (prospected) policy mix is crucial to ensure that the mix is consistent, coherent, credible and comprehensive. This is especially important in the context of shared refrigeration, as the findings of the current research have shown that it is of the utmost importance that the government will be a reliable, credible and trustable actor when it comes to shared refrigeration. Poorly performing policy mixes could therefore be a major obstacle for successful shared refrigeration initiatives to emerge (cf. De Jesus and Mendonça, 2018).

6.3.1.2 Monitoring and evaluation

After implementation, the dynamics caused by certain policy mixes can be complex and perhaps surprising. It has been noted, for example, that policies and regulations that do not specifically focus on the implementation of IS were often important drivers for IS realization (Lybaek et al., 2021; Desrocher, 2004; Desrocher & Sautet, 2008). Continuously monitoring and evaluating the policy mix is very important to keep track of the effects of the mix. Monitoring and evaluation is also crucial to ensure the policy mix will be and remain effective in the dynamic world of sustainability policy-making (Kemp et al., 2007; Loorbach et al., 2007; Kemp, 2011).

All in all, it will be good practice for governments to carefully consider which mix of policy instruments and strategies will be employed to facilitate shared refrigeration or other sustainable initiatives, and to monitor the effects of the mix after implementation. The framework by Rogge & Reichardt (2016) as shown in Figure 6.1 will be a useful tool in these efforts.

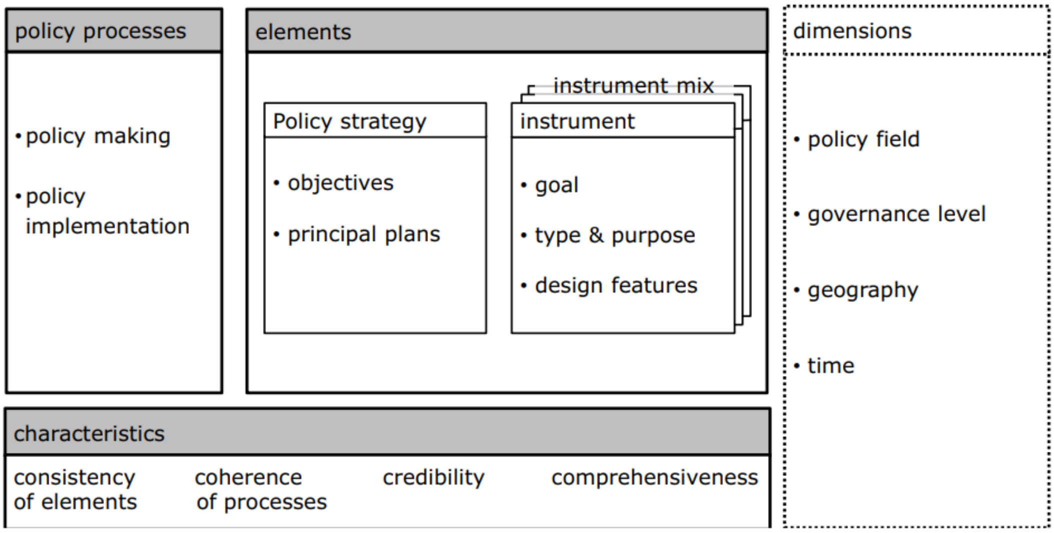

Figure 6.1. Building blocks of the extended policy mix concept. Source: Rogge & Reichardt (2016).

6.3.1.3 Shared refrigeration as part of the environmental policy mix

The results of the current research have indicated that sustainable refrigeration is currently not a topmost priority for the Dutch government. As several interview participants indicated, the focus of the government lies mainly on stimulating sustainable heating, moving from gas to electricity as a source of power, and waste chains. Interestingly, including sustainable refrigeration in the list of focus areas could have a positive effect on other terrains. The current research has shown very clearly, for example, that local business associations are underperforming in terms of acting as breeding grounds for sustainable collaboration initiatives. The reasons for this underperformance seem to be that entrepreneurs do not like to engage in efforts that are not their core business. As shared refrigeration might offer financial advantages, which are interesting for entrepreneurs, it may be an incentive for entrepreneurs to join forces in local business associations.

Regardless of whether the shared refrigeration initiative will be successful, it is likely that bringing entrepreneurs together in a symbiosis-oriented setting will spark unexpected fires and perhaps result in unexpected sustainable partnerships (cf. Ormazabal et al., 2018; King et al., 2020; Lybaek et al., 2021; Chen, Zhou, Zhou & Xue, 2017; Chen, Xu & Zhou, 2017). Interview participants in this study have indicated that such unexpected symbiotic partnerships have in fact resulted from symbiosis-oriented meetings between entrepreneurs based in the same industrial park. Moreover, more interaction between entrepreneurs in local associations offers good possibilities for continuous communication about sustainable technologies, which has shown to be important for the emergence of IS initiatives (Veleva et al., 2015; Tudor et al., 2007). An added benefit is that increasing the knowledge base in a company improves that company's absorptive capacity (Cohen and Levinthal, 1990), implying that the more knowledge a firm has, the more successful it will be in assimilating newly acquired knowledge that can be used in other sustainable practices (Ar and Baki, 2011; Jantunen, 2005; Zahra and George, 2002; Zeng et al., 2010; Schøtt & Sedaghat, 2014).

Of course, this reasoning can also be turned around - if entrepreneurs are incentivized to join local business associations for other reasons than setting up a shared refrigeration system, shared refrigeration may be considered as a "byproduct" of the joint effort, as an unexpected but likely advantageous side-effect of the policy mix.

6.3.2 Adoption and diffusion

Assessing factors that influence the adoption and diffusion of shared refrigeration is useful to predict the technology's success and viability. The theory by Rogers (1995) has been a very widely used framework for predicting and analyzing adoption and diffusion patterns. However, it should be noted that the theory by Rogers (1995) has been related mostly to adoption of innovations of a less complicated nature than industrial symbiosis. As symbiotic collaborations entail an interplay of many actors who each have, to a certain extent, different values, beliefs and perceptions, the adoption and diffusion process may turn out to be more complex than can *a priori* be predicted. Whereas Rogers (1995) dedicates a chapter to organizational innovativeness, he does not take into account these complex symbiotic dynamics *between* different organizations.

6.3.2.1 Proposed two-layer approach

However, one might follow the following line of reasoning. As SMEs are usually led by one or very few firm leaders who take important decisions about their company's future on their own, as opposed to larger firms that tend to have a larger management board or even a wide range of shareholders who are co-deciding on management decisions, the companies could be regarded as one "consumer entity". Companies can then be considered "consumers" of a technology, for whom the dynamics of Rogers' framework are likely to apply individually. Based on the findings of the current research and earlier literature, it has been argued that local champions play a crucial role in the development of shared refrigeration systems. These champions, which can be firms or other organizations, introduce and promote the technology to their potential symbiotic partners, but first have to decide themselves whether or not to invest in the concept. Therefore, it can be proposed that the innovation-decision has two layers. First, the champion makes the decision that they intend to adopt the innovation. Then, the other partners make the decision whether or not to join the champion's initiative. For both decision processes, Rogers' framework can be argued to apply. Caution must be taken as the two layers have a degree of interrelation - naturally, the concept will not be viable if too few partners collaborate, in which case the decision of the champion to engage in the concept will likely be revoked. Further research is needed to assess these interrelations.

Figure 6.2 displays variables determining the rate of adoption as proposed by Rogers (1995). Using the proposed two-layer approach of two optional innovation-decisions, the champion and its potential partners in a shared refrigeration initiative are confronted with the same variables, which will be elaborated on in the following subsections.

6.3.2.2 Perceived attributes of innovation

Rogers (1995) argues that several *perceived attributes of an innovation* influence the adoption rate of the innovation. He argues that the adoption rate goes up if there is a **relative advantage** to be gained by adopting the innovation, for example if (i) there are more economic advantages, (ii) an increase in social status can be gained by adopting the innovation, (iii) incentives are provided, or if (iv) mandates are set by governments. For shared refrigeration, the economic advantages have not been clarified yet. It is important that this be done in order to ensure a good adoption rate of the technology (cf. Corder et al., 2014; Bossle et al., 2016; Chappin et al., 2020; Montalvo Corral, 2003). Rogers (1995) argues that adoption rates slow significantly if consumers have difficulty seeing the advantages of adopting the innovation. The findings of the current research confirm that informing stakeholders about the benefits of shared refrigeration is crucial to a successful adoption process. Therefore, solid communication about potential benefits will be very important.

Participants of the current research confirm that an increase in social status would be a reason for which firms would engage in sustainable initiatives like shared refrigeration. Indeed, over the last couple of years sustainability has become an important topic in society, and research has shown that firms are eager to label their production as sustainable (Prieto-Sandoval et al., 2018, Bossle et al., 2016). The presence of government-provided incentives and mandates is currently low. If the government decides to encourage shared refrigeration, these incentives and mandates will be good measures to increase adoption rates. Participants of this study have indicated that they expect that subsidies and mandates will be useful government instruments to encourage the adoption of shared refrigeration, and this is in line with research into the adoption of eco-innovations (Boons et al., 2011; Corder et al., 2014; Bossle et al., 2016; Ghisetti & Montresor, 2020). Mandates and subsidies can be created either directly to favor shared refrigeration, or indirectly to weaken the existing regime and make space for a sustainable transition (Weber, 2014). However, too stringent policies have also shown to affect the adoption of eco-innovations negatively (Montalvo Corral, 2003). Participants of the current studies also see this as a risk. Therefore, it is important to apply policies very carefully, and to properly assess the effects of policy mixes as described in the previous section.

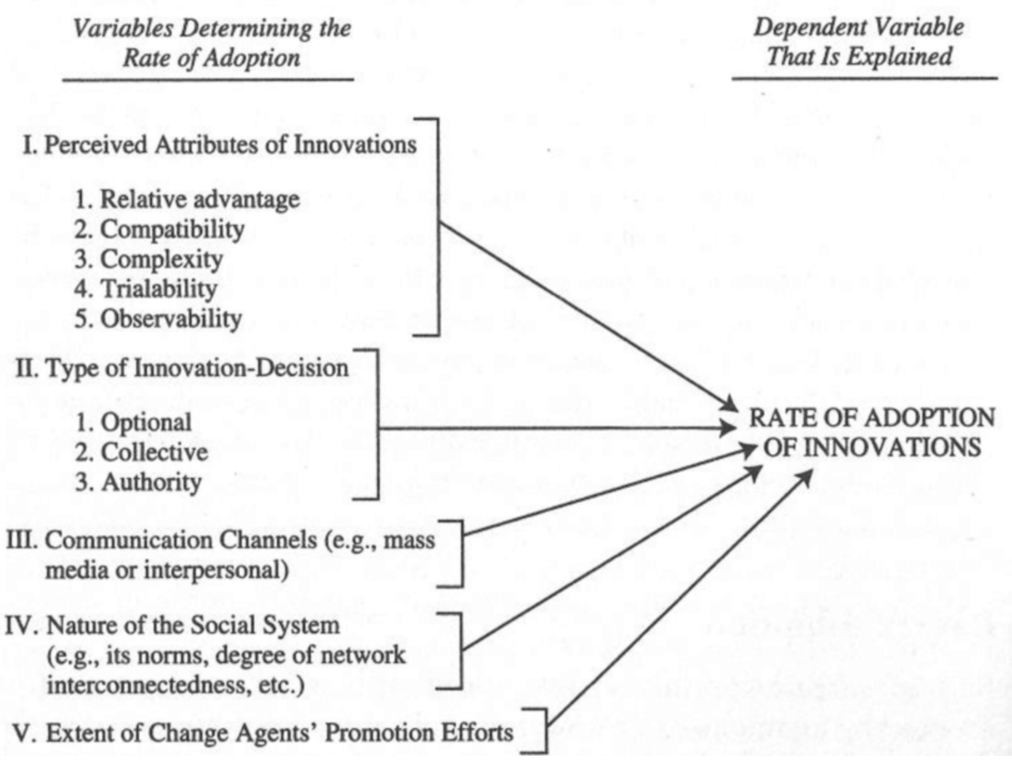

Figure 6.2. Variables determining the rate of adoption of innovations. Source: Rogers (1995).

Rogers (1995) also argues that adoption rates go up if there is good **compatibility** with needs, values and beliefs. It is clear that all participants of the current study indicated they hold the value of sustainability and believe that it is important to take care of the environment. If the sustainable advantage of shared refrigeration can be established, the technology will be compatible with this.

Triguero et al. (2014) showed that firms that value green innovation higher are more likely to be early adopters of a technology. This indicates that this type of company might be well suited to be a local champion. During the current study, a participant who mentioned valuing sustainability highly proposed that his company would be interested in taking the role of local champion. This confirms the findings of Triguero et al. (2014). Compatibility with customers' needs is a complicated topic. While a shared refrigeration system will fulfill customers' refrigeration demand, the findings of this study indicate that it might also make them more dependent and less sure about the quality of their production. This perceived lack of control over the innovation might counteract adoption (Montalvo Corral, 2003). Rogers (1995) argues that customers might not be aware they have a need for adoption, and should be pointed out the benefits.

Trialability is another issue, as even trials with shared refrigeration will likely require high investments and a large degree of coordination. This might be an obstructing factor for the adoption rate and stresses the need for government subsidies and inclusion in trial programmes like Fieldlabs (as also indicated by several participants). Nevertheless, as the **observability** of the results achieved by shared refrigeration will likely be good, adoption rates might increase significantly if first trials prove to be successful (Boons et al., 2011; Bossle et al., 2016).

6.3.2.3 Other factors

Rogers (1995) indicates that **communication channels** are important instruments through which adoption rates can be influenced, as well as the **nature of the social system** and the **extent of change agents' promotion efforts**. Again, this stresses the need for a clear communication structure (see also Boons et al, 2011) and the importance of putting effort in the system's promotion (see also Chappin et al, 2020). Findings of this research indicate that vertical communication channels are already in place, but horizontal channels should be improved. The nature of the social system is such that sustainability is valued, but collaboration between SMEs is still insufficient. This can be improved using facilitation strategies that were described in Section 6.2.

6.3.3 Sustainable transitions

The scientific field of sustainable transitions investigates how sustainable technologies emerge from innovation and eventually overtake existing technological regimes. Research has shed light on the complicated dynamics that surround technological transitions, and the findings may be useful for the development of shared refrigeration technology as well. This section will evaluate shared refrigeration technology in the light of the so-called multi-level perspective (MLP), and will draw from sustainable transitions literature to derive recommendations for facilitation of shared refrigeration.

6.3.3.1 A weakening regime

The multi-level perspective (MLP) is often used to describe transition dynamics. It consists of three levels: (i) the socio-technical landscape, (ii) the socio-technical regime, and (iii) the niche-innovations level. A visualization of the multi-level perspective can be found in Figure 6.3. New technologies enter the framework at the niche innovation level. The figure shows that at the niche innovation level, many different smaller innovations take place at the same time, which eventually after a complex selection process evolve into a dominant design. This dominant design may then challenge the incumbent regime, and can eventually overturn it if windows of opportunity arise as a result of pressures that might occur on all three levels of the MLP (Berkhout et al., 2004; Smith et al., 2005).

Shared refrigeration is a new and unexplored field of science, and therefore it has not gained enough status to be considered a niche innovation yet. Therefore, the dynamics of the MLP should be viewed as future scenarios that will become important to take into account when shared refrigeration has gained enough ground to be considered a niche innovation. However, it will be interesting to take a forward-looking view and explore what these MLP dynamics surrounding shared refrigeration are likely to be, to be able to adapt strategies to these predictions.

When in the stage of being a niche innovation, shared refrigeration could be in the position to challenge the incumbent regime of fragmented, individually owned industrial refrigeration equipment. This regime finds itself in the socio-technical landscape of refrigeration technology, or even broader, the energy sector. Several landscape pressures can already be identified according to the findings of the current research: the phasing out of synthetic refrigerants, which increasingly forces firms to switch to natural refrigerants; the Dutch energy transition, which forces businesses to rethink their energy consumption. Furthermore, regime pressures such as high initial investments and maintenance costs that are associated with fragmented refrigeration systems; and personnel shortages in the technical sector, can be identified. Such pressures may weaken the incumbent regime, making space for novel technologies like shared refrigeration to gain momentum and perhaps become a new dominant standard.

The presence of complementary innovations that are mutually reinforcing each other can lead to a gain in momentum of a socio-technical innovation (Geels et al., 2017). In the context of shared refrigeration, this implies that developments in for example heat and cold storage technology, district heating, and new business models might contribute to the potential success of shared refrigeration. Geels et al. (2017) also argue that social acceptance and business support are crucial for a successful transition, and that forcingly phasing out existing technologies can resolve technological lock-in and make space for new innovative technologies. The results of the current research show that the planned phasing out of synthetic refrigerants is indeed forcing businesses to shift to other technologies. Moreover, the congestion problems that plague the electricity network are increasingly calling for other, smarter energy solutions. The congestion problems are expected to worsen as a result of the Dutch energy transition where natural gas is being abandoned as an energy source. These factors open up windows of opportunity for new systems and technologies like shared refrigeration. It can therefore be argued that there is a chance for shared refrigeration to take advantage of these windows of opportunity to gain momentum, and it is useful to assess how this can be facilitated.

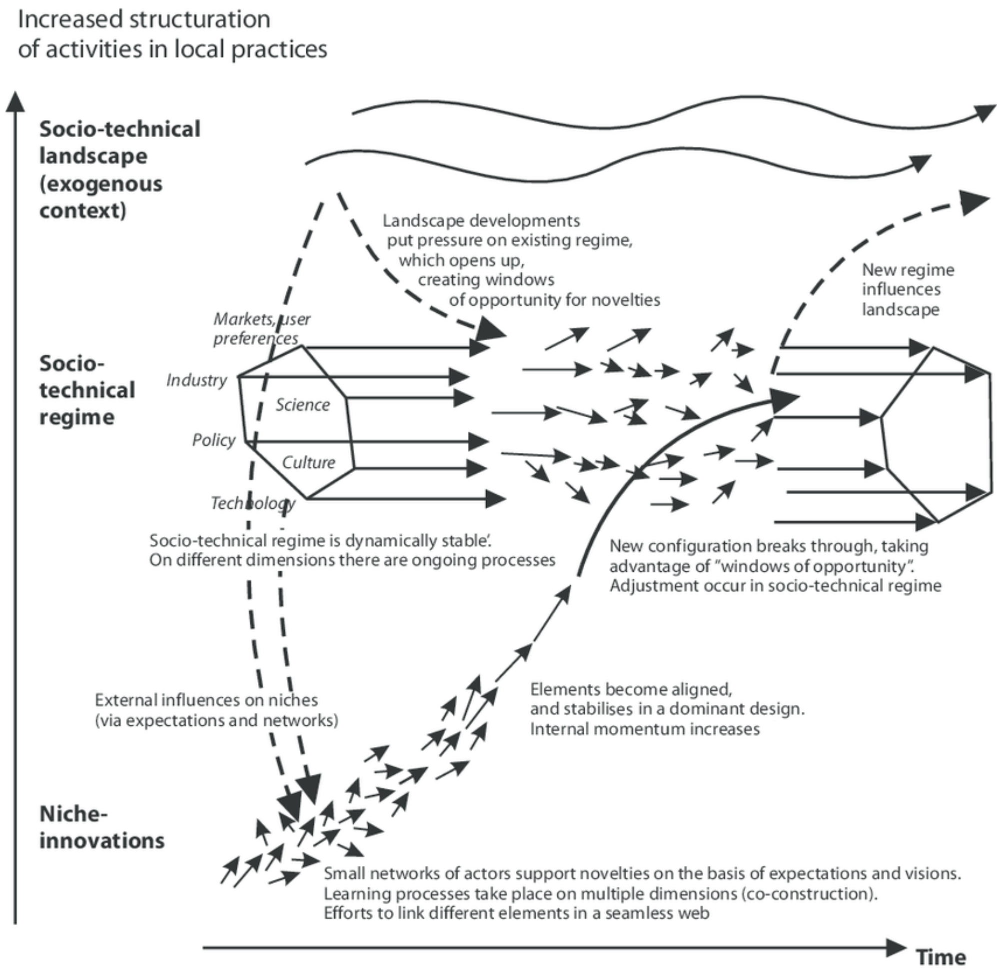

Figure 6.3. Multi-level perspective on socio-technical transitions. Source: Geels (2002).

6.3.3.2 Actively facilitating a transition

The important role of social acceptance and business support is confirmed by Loorbach et al. (2017), who highlight the importance of reframing problems, and visioning - creating and reinforcing a belief in the new technology, to motivate actors to engage themselves in the process of developing it. The creation of visions, scenario-building and backcasting are good tools to achieve this (Loorbach et al., 2017; Quist, 2013). Such efforts, which contribute to social acceptance, storytelling, and shaping and voicing expectations about shared refrigeration, will therefore have a favorable effect on the technology's growth. Moreover, experiments and evaluations are crucial to unravel the implications of the new technology, and shed more light on how a transition could be facilitated (Loorbach et al., 2017). This is in line with the findings of the current research, which have already shown that proper assessments of advantages and other implications of shared refrigeration systems will be very important for the technology's success.

Furthermore, Bidmon & Knab (2018), who investigated the role of business models in socio-technical transitions, argue that business models that act as intermediaries between technological niches and socio-technical regimes facilitate the breakthrough and stabilization of new technologies. Such business models "support the stabilization of rules and structures around a niche technology because they (i) facilitate the articulation of expectations and visions among niche actors, (ii) allow the demonstration of the value of novel technology to regime actors, and (iii) link technology to more and more actors and support the emergence of a value network around the technological innovation" (Bidmon & Knab, 2018, p. 907). In the context of shared refrigeration, the business model may thus play an important role in the success of the technology. Several interview participants indicated that a suitable business model would be to let an investment collective build the shared refrigeration system, and subsequently have consumers of cold energy pay per kWh that they consume. Consumers will not have to carry the burden of large initial investments anymore which is inevitable if they would have to buy all of their refrigeration equipment themselves. Such a business model bridges the gap between the incumbent regime, and the new technology, as it makes a transition to the new system easier. Consumers themselves do not have to worry about realizing and maintaining the equipment anymore, while they keep receiving the same output result as the current regime technologies give them. This will present them with significant advantages.

Figure 6.4. Characteristics of the sustainable business model archetype "deliver functionality, rather than ownership". Source: Bocken et al. (2014, p. 51).

This is illustrated by Bocken et al. (2014), in whose typology this business model fits the archetype of "delivering functionality rather than ownership" (see also Figure 6.4). Typical for this archetype is that it can change consumption patterns (Bocken et al., 2014), leaving more investment capital for consumers to improve other processes. It may also incentivize manufacturers to increase the longevity and reparability of the product (Bocken et al., 2014). Noteworthy is that it has been found that such business models carry the risk of consumers having uncertainty about whether the product will live up to their expectations (Catulli, 2012). The results of the current research indicate that this will indeed be a barrier to the success of shared refrigeration. Therefore, it is important to make clear to consumers that this type of business model is not new - public service companies like electricity, gas and water providers have been using similarly structured business models for a very long time. The stability and proven effectiveness of such business models will likely have a favorable effect on the success of shared refrigeration. The business model will act as an intermediary between existing technological practices (as end users will not notice many significant differences in their production methods) and novel technologies (the central refrigeration plant and distribution network). As Bidmon & Knab (2018) argue, such business models tend to drive transitions, and can therefore be considered to be favorable for the success of shared refrigeration technology.

Another way in which a technological transition can be facilitated, is by investigating the process by which a “dominant design” emerges from a broader range of niche innovations (which is illustrated near the center of Figure 6.3). Taking this process into account will allow actors to focus their resources on the configuration of a shared refrigeration system that will be most likely to become the new regime. The next section will elaborate on how this can be achieved.

6.3.4 Design dominance

The scientific field of design dominance investigates the phenomenon where certain technologies become dominant (the “dominant design”) in an industry (Utterback & Abernathy, 1975; Gallagher & Park, 2002), as a consequence of complex processes in which several alternatives compete until a certain hierarchy emerges (Clark, 1985). Investigating the process of a dominant design emerging from a range of different configurations of shared refrigeration systems will be valuable once shared refrigeration technology has started gaining terrain. By making predictions about the dynamics of this process, strategies can be adapted for more successful and efficient growth of the technology.

6.3.4.1 Relevance of assessing the dominance process

Looking back on the current research, it has already been noted that at least two configurations of a shared refrigeration system are possible (the single-loop and double-loop variants described in Section 4.4.6), and participants of the main interview round suggested that more configurations are interesting to explore. As all of these different configurations have different implications for a broad range of factors, it is worth investigating which design will be most likely to achieve dominance, so that subsequent efforts and policies can be shaped to facilitate the implementation of that particular variant. For example, the findings of the current study indicate that windows of opportunity for implementing shared refrigeration are scarce, and that their occurrence depends on a complex interplay of many different factors. Continuous scanning for opportunities is of vital importance for the success of shared refrigeration. However, different configurations likely require different factors to be present in potential implementation locations (for example, a configuration that includes coupling to an urban heating grid requires the vicinity of a residential area, while a configuration that would be coupled to an industrial heating grid requires the presence of businesses demanding low-grade heat). If all possible configurations of shared refrigeration systems would be taken into account, scans will become extremely complicated and perhaps impossible to conduct. It might be a better strategy to focus on those configurations that are most likely to be successful and become the dominant standard in the future. Therefore, predictions about which configuration this will be are very valuable, and taking the dominance process into account will likely be good practice.

6.3.4.2 Phases of dominance process

A framework for understanding dominance processes, also referred to as “battles for technological dominance” was conceived by Suarez (2004). The framework builds on previous research into factors that influence technological dominance battles. The author argues that the framework applies mostly to information and telecommunication industries, but indicates that it may well apply to other fields as well (Suarez, 2004). The framework might be used as a tool to evaluate shared refrigeration in the light of dominance battles. The framework by Suarez (2004) describes success factors by which certain technological designs might achieve dominance, offering an interesting extension to the main frameworks that were used to guide the current research. Table 6.7 shows the key factors of success for achieving dominance in relation to the five different stages of the dominance process as described by Suarez (2004).

Table 6.7. Phases of the dominance process and key factors of success. Based on Suarez (2004).

Factor type	**Dominance factor**	**Phase I** R&D build-up	**Phase II** Technical feasibility	**Phase III** Creating the market	**Phase IV** Decisive battle	**Phase V** Post-dominance
Firm level	Technological superiority		X			
	Credibility, Complem. assets	X			X	
	Installed base				X	X
	Strategic manoeuvering			X		
Environmental level	Regulation		X			
	Network effects and switching costs				X	X
	Regime of appropriability	X				
	Characteristics of technological field	X				

Pioneering R&D
First working prototype emerges
First launch of commercial product
Clear early front-runner appears
One design becomes dominant

When considered in the light of the framework, the concept of shared refrigeration may find itself in Phase I: R&D build-up, or Phase II: Technical feasibility. This classification can be based on several arguments. Firstly, early studies into the technology's viability have already been conducted, of which the current research is part. Secondly, the existence of working prototypes depends on the breadth of the definition that is used for shared refrigeration, and while shared refrigeration technology has not been applied on a large scale, smaller distribution networks of refrigerants are already in use. As earlier indicated by the findings of the current research, these systems are similar in structure and may serve as prototypes for the large-scale system.

If shared refrigeration will be implemented in practice, the framework by Suarez (2004) will be useful in keeping track of the dynamics of the dominance process that will surround shared refrigeration. As the framework offers an overview of which factors are especially important in each stage, it offers a useful tool to make predictions about which configuration of shared refrigeration will most likely achieve dominance.

6.3.4.3 Current factors

As can be seen in Table 6.7, three factors are key to the success of a technological design in Phase I: the design's credibility and complementary assets, the presence of a good regime of appropriability, and appropriate characteristics of the technological field. In Phase II, there are two factors: a design's technological superiority and the presence of favorable regulation and institutional intervention. Having established that shared refrigeration technology currently finds itself in one of these phases, it is possible to shed light on their associated factors to predict early dynamics of the (early stages of the) battle for dominance.

With respect to the factor of **credibility and complementary assets**, the reputation and established capabilities of firms developing new technological designs have been shown to affect the likelihood of that design achieving dominance (Teece, 1986; Suarez, 2004; Van de Kaa et al., 2011). Furthermore, Van de Kaa et al. (2011) concluded from a review of literature on interface formats that financial strength of the format supporter affects the format's likelihood to achieve dominance. Extending these findings to shared refrigeration, it can be argued that for parties that have a good reputation, established innovative capabilities, and strong financial backup, it will be easier to attract investors. The technology will then be more likely to gain momentum. Several participants in the current research indicated that governments especially have a position that holds much credibility, as they represent a generally stabilizing party in collaborations with more unstable entrepreneurial actors. Government support for a particular configuration of shared refrigeration systems will therefore likely give that configuration a significant strategic advantage.

During Phase I, the presence of a **strong regime of appropriability**, where solid instruments are in place to capture rents, has also shown to positively affect the likelihood of that design achieving dominance (Teece, 1986; Suarez, 2004). Van de Kaa et al. (2011) concluded that for interface formats, capturing scarce assets early in the development process can create a competitive advantage with respect to other actors. For shared refrigeration, this could imply that configurations that have promising business models that ensure a good rent capture, and are successful in capturing development permits (that subsequently cannot be obtained by other parties), will be likely to have a strategic advantage. As these characteristics will create a higher degree of certainty regarding payback rates and financial stability and will therefore probably also facilitate finding investors.

Regarding the Phase I factor of **characteristics of the technological field**, research has shown that the number and power of actors in a technological field, as well as the balance between competition and cooperation, the market structure, the rate of technological change, the amount of uncertainty, and the number of alternative options available, have an effect on the likelihood of that design achieving dominance (David & Greenstein, 1990; Garud et al., 2002; Suarez, 2004; Van de Kaa, 2011). A bandwagon effect and network externalities might also occur and affect the outcome of dominance battles (Van de Kaa et al., 2011). In the context of shared refrigeration, this bandwagon effect and network externalities are especially important as the technology will likely encounter a large degree of path-dependency. Parties such as governments will be involved in multiple initiatives, and if they support a certain configuration, it is very likely that the other parties involved will follow suit. Other configurations will then be less likely to be supported, likely pushing them to the background. This is similar to another factor identified by Van de Kaa et al. (2011), who also concluded that influential adopters ("big fish") can be greatly beneficial to the technology's promotion. Adoption of shared refrigeration by influential businesses, or integration of the technology in government strategy, might lead to higher adoption rates. This will give that particular configuration a significant strategic advantage. As the government is a crucial actor in the process, and as it might decide to only provide subsidies to certain configurations, this effect can be strong. However, it should be noted that this entirely depends on the attitude the government will take.

In Phase II, **technological superiority** of a technology is considered an important factor. Technological superiority of a particular design can have an effect on the likelihood of that design achieving dominance (although this is not always the case) (Suarez, 2004). Van de Kaa et al. (2011) concluded that backwards compatibility of interface formats can increase their adoption rate and the likelihood of achieving dominance. In the context of shared refrigeration, this might hold that if more existing pieces of equipment can be connected to the shared refrigeration grid in a particular configuration, that configuration likely has more chance of success.

With respect to **regulation and institutional intervention**, Suarez (2004) argues that laws, regulations, and other kinds of interventions by public bodies or influential private organizations can affect the outcome of a dominance battle. The findings of Van de Kaa (2011) confirm this reasoning, and those of the current research also seem to point in the same direction, as the government is a very strong and influential party in establishing shared refrigeration systems. A configuration that has the government's preference will have a clear and significant advantage over other configurations.

6.3.4.4 Factors in later stages

In later stages, strategic manoeuvering, building a large installed base, and exploiting network effects and switching costs are important for a design to achieve dominance (Suarez, 2004; Van de Kaa et al., 2011). Van de Kaa et al. (2011) conclude that for interface formats, a supporting firm's learning orientation, flexibility of the technology, a good pricing, marketing and distribution strategy, strategic timing of entry, and commitment may affect the outcome of the dominance battle, as a large absorptive capacity reduces the likelihood of lock-out and strengthens the likelihood of a design to achieve dominance. The findings of the current research indicate that these factors also apply to shared refrigeration, and therefore it is likely that these factors can be used in the future to predict the dynamics of the dominance battle. Further research will be necessary to keep track of these dynamics.

6.4 Limitations to the current study

Several limitations have been identified for the current research. Firstly, the current research focuses on SMEs based on Dutch industrial parks in particular. This means that the findings of this research might not apply to larger companies, businesses located in residential areas, or businesses located in other countries.

During the concept consolidation phase, two possible arrangements of industrial shared refrigeration systems arose from the first interview round (single-loop and double-loop). In the second interview round, some participants suggested several modifications in addition to these two configurations. However, due to time constraints, only one variant could be used in the current research. This implies that some findings may not apply to other configurations of shared refrigeration systems. However, as the majority of findings relate to the emergence process of shared refrigeration-related collaborations which will likely be very similar regardless of which configuration will be implemented, most of the findings of the current research will retain their scientific and practical value.

The number of interview participants was limited (three in the first round and thirteen in the second round). Although such limited numbers of participants are not uncommon in qualitative research, more participants will always lead to more data and to more detailed results. Due to the limited number of participants and semi-structured nature of the interviews, no reliable quantitative conclusions can be drawn from the results of this research. However, this was never the goal of the study, as the objective of the research was to provide a qualitative exploration of the topic of shared refrigeration. Other researchers are encouraged to conduct quantitative studies to validate the findings of the current research.

Some participants indicated that they did not have sufficient knowledge or time to answer certain questions in full capacity. This implies that there may still be details that have not been uncovered in the current research. Follow-up researchers are encouraged to validate and extend the findings of this research.

Another limitation lies in that the study was conducted by a single researcher, implying that the data analysis was dependent on the interpretation and judgment of the researcher. As the interviews were conducted in Dutch, translations needed to be made that could also have been subject to subjective factors. This might have effects on the validity of the research. Other researchers are encouraged to review the methodology and validate the findings.

6.5 Managerial implications

The findings of this study are valuable for managers and firm leaders who wish to increase their awareness of sustainable refrigeration opportunities, as well as to increase their understanding of the value of interfirm collaborations in increasing their firm's sustainability and profitability. The findings provide recommendations for all stakeholder groups to facilitate collective sustainable initiatives, and actors are highly recommended to take note of the possible measures they can take to move towards a more sustainable and integrated operational structure.

This exploratory study aims to pave the way for more extensive research and development in the field of shared refrigeration or similar concepts. Managers and other actors may use the findings of this research as a base on which to build more scientific studies, experiments, and business case analyses, which are a crucial aspect to the technology's eventual success. Perhaps the most valuable contribution of this research is to increase the knowledge base of managers, and provide them with a new lead that they may grab on to in order to innovate. As Sáez-Martinez et al. (2016) and Ha et al. (2021) indicate, firms that have a more solid knowledge base, see the value of collaboration, and are better able to identify opportunities, are more likely to engage in eco-innovation than firms that stick to their traditional knowledge and practices. As the world is moving rapidly towards sustainability, eco-innovation will become an increasingly important aspect of business. Therefore, it is crucial that managers and firm leaders keep increasing their knowledge and awareness of sustainable solutions. This study has aimed to contribute to that cause.

The findings of this study will help managers become aware of the complex dynamics that surround shared innovation processes. Shared refrigeration requires collaboration across multiple layers of management and many different stakeholders. This study has aimed to uncover the factors that determine these complex dynamics, to help managers strategize how they can best approach engagement in shared refrigeration initiatives. By increasing managers' understanding of the dynamics surrounding shared refrigeration, this study hopes to contribute to better adoption rates of not only this concept, but also other forms of shared sustainable innovation that have similar characteristics.

7 Conclusion

As stated in Section 1.2, the objective of the current research has been to shed light on the barriers and opportunities that exist for a potential implementation of the concepts of shared refrigeration in Dutch industrial parks, and to to provide recommendations for businesses, governments and academia on how implementation of shared refrigeration among SMEs in Dutch industrial parks can be facilitated. In order to achieve this objective, a literature review was carried out, after which stakeholder interviews were conducted to gather data about barriers and enablers currently in place in the Dutch context. To ensure the quality of the findings, a preparatory round of expert interviews was conducted before the main round of stakeholder interviews, to create a solid conceptualization of shared refrigeration that served as a reference for the participants of the main interview round to base their judgments on.

Three subquestions were used in the process to come to an answer to the main research question: *"How can the implementation of shared refrigeration among SMEs in Dutch industrial parks be facilitated?"*. Each of these three subquestions will be answered below.

SQ1: Which barriers hamper and which enablers facilitate the implementation of utility sharing and industrial symbiosis among SMEs?

In answering this subquestion, a literature review was conducted to investigate which barriers and enabling factors were found in prior research on shared refrigeration and district cooling, and engagement of SMEs in industrial symbiosis and eco-innovation. Potential barriers to the implementation of utility sharing and industrial symbiosis among SMEs that were found in literature are (i) insufficient finances or financial incentives, (ii) insufficient technological knowledge or codification, (iii) inadequate provision of information, (iv) lack of time to invest in IS engagement, (v) difficulty finding suitable locations for implementation, (vi) lack of commitment by firm leaders, (vii) lack of public awareness and interest, (viii) having a short-term focus, (ix) distrust of potential symbiotic partners, (x) fear of output quality issues, (xi) fear of not being worth the investment, and a (xii) lack of cooperation between public and private sector.

Enabling factors were identified using the framework of Mortensen & Kørnøv (2019), who provided a dedicated review of critical factors for the emergence of industrial symbiosis. It was found that the extent to which contextual factors are enabling for the emergence of industrial symbiosis play an important role in IS emergence processes, as well as the roles, activities, and characteristics held by certain actors. Contextual factors that play a role are (i) an enabling policy environment, (ii) a history of prior collaborations and exemplary initiatives, (iii) the availability of funding, (iv) good physical and digital infrastructure for collaboration, (v) good timing and patience, (vi) geographical proximity, and (vii) knowledge of each other's pool of resources. The extent to which actors take on certain roles, have certain characteristics, and engage in certain activities, was found to have an influence on the success rate of IS emergence.

SQ2: Which barriers hamper and which enablers facilitate the implementation of shared refrigeration in Dutch industrial parks?

To answer this subquestion, stakeholder interviews were conducted where participants were asked to describe what barriers and enablers they saw in the Dutch context. The framework of Mortensen & Kørnøv (2019) was used as a guiding structure, as well as the list of barriers for the engagement of SMEs that was found in scientific literature during the literature review. Barriers that were identified are: (i) a funding gap in the initiation phase, (ii) the long investment horizon, (iii) uncertainty due to a lack of financial and sustainable assessments, (iv) lack of prior experiences, (v) incapability of local business associations, (vi) inadequate information sharing, (vii) a lack of public awareness, (viii) a fear of being dependent, (ix) a fear of competitive threats, (x) scarcity of implementation opportunities, (xi) strict policies for complementary systems, and (xii) businesses having a short-term focus.

Enablers that were identified are: (i) the currently favorable policy climate, (ii) congestion problems in the electricity network, (iii) the currently favorable investment climate, and (iv) active knowledge sharing by governments and consultancy firms.

SQ3: How can the barriers to the implementation of shared refrigeration in Dutch industrial parks be overcome?

This subquestion was answered using a combination of the results of the stakeholder interviews and findings from existing scientific literature on how to overcome barriers to the engagement of industrial symbiosis and eco-innovation. Interview participants noted several potential ways of overcoming barriers. These potential strategies were compared to and supplemented with findings from existing scientific literature in order to come to a substantiated series of recommendations for stakeholders on how they might act to reduce the barriers currently in place for the implementation of shared refrigeration in Dutch industrial parks. It was found that there are many potential ways to reduce or remove the barriers to implementation of shared refrigeration in Dutch industrial parks, most notably by conducting scans for opportunity identification, conducting business case analysis to come to financial and sustainable assessments, closing the funding gap in the initiation phase, disseminating experiences from similar projects, setting up and/or strengthening the capabilities of local business associations through knowledge sharing, and creating partnerships with governments, consultancy companies and research and education institutions.

RQ: How can the implementation of shared refrigeration among SMEs in Dutch industrial parks be facilitated?

The answer to the main research question follows from the combination of the barriers with the facilitation strategies. Although some enabling factors might facilitate an implementation of shared refrigeration among SMEs in Dutch industrial parks, there is still a wide range of barriers in place for the technology. All stakeholders can commit themselves to reduce or remove these barriers through a wide range of strategies that have been discussed in the research. Facilitating the implementation of shared refrigeration among SMEs in Dutch industrial parks requires the combined effort of governments, businesses, and academia to overcome the barriers and strategically move to a collaborative future.

8 Recommendations

This chapter provides a number of recommendations for future research, for practical applications, and for the study programme of which this thesis project is the finishing part.

8.1 Scientific recommendations

As explained before in Section 6.4, this study has been subject to several limitations. Future research may address these limitations by conducting studies based on input from a higher number of participants, either qualitatively or quantitatively. A higher number of participants will remove noise and allow the researcher to draw quantitatively valid results, which can provide stronger claims about the potential of the technology of shared refrigeration. Moreover, a structure is recommended in which the results are judged by multiple researchers, preferably of a diverse nature. This may reduce the effect of potentially biased judgements and make for more accurate results.

The current study focuses on one configuration of shared refrigeration, namely one that has a double-loop configuration, and employs an infrastructure to distribute cold refrigerant to firms. However, other configurations of a shared refrigeration system are possible, like the single-loop variant that was discussed in Chapter 4. During the main interview round, several participants proposed that it might also be interesting to create an infrastructure to "collect" waste heat from fragmented refrigeration installations. This connection "on the warm side" might have advantages in that the infrastructure will be less expensive to build. On the other hand, it will not lead to lower initial investments for partners. It is recommended that further research be carried out into this configuration, to assess the technical and economical viability.

The findings of this study indicate that for the success of shared refrigeration, it is of critical importance that scans are performed to identify potential implementation sites. Hereby, researchers should take a broad range of elements into account, including the presence of sufficient partners with a similar temperature demand, the presence of potential heat coupling appliances, as well as the expected "filling-up" time of an industrial park. It is highly recommended that the technological scope is kept broad, to allow for a flexible technical set-up. For example, some locations might benefit from an extensive heat or cold storage facility, while others might be structured in a way that it may be more interesting to investigate the pairing-up of businesses on the "warm side".

As indicated in Section 6.2.3, it is crucial that policymakers investigate the prospective effect of the policy mix that will affect technological change in the context of shared refrigeration. It is recommended that future research be conducted to predict the dynamics and potential effects of different combinations of policy instruments and implementation strategies, so that a "best practice" approach can be recommended to public bodies and other stakeholders.

Finally, it is recommended that research be conducted into other forms of more sustainable refrigeration. In this study, several participants indicated that refrigeration technology is rather slowly moving forward, and there is a shortage of personnel that have knowledge of innovative and new technologies, while refrigeration accounts for an increasingly large share of energy consumption worldwide. The large gains that can be achieved are largely unexplored and call for significantly more research. Special focus should be laid on collaborations and new sustainable business models, as several participants indicate that there is much more to be gained in realizing integrated solutions than in improving the technical performance of refrigeration equipment.

8.2 Practical recommendations

While practical recommendations for stakeholders surrounding shared refrigeration have already been provided in **Table 6.6**, the most critical points of interest will likely be the following.

Increasing the knowledge of sustainable solutions among installation companies will likely be a strategic and effective move. Consumers usually have very limited knowledge of refrigeration systems and turn to installation companies to provide them with solutions. Because installation companies are significantly smaller in number than the range of consumers, a snowball effect can be accomplished by focusing on the improvement of their knowledge base. This task can be taken on by public bodies or sector associations (most notably the NVKL, which is the sector association of installation companies in the refrigeration field). A good option is to put primary focus on market leaders, as they are determining factors in the behavior of smaller installation companies.

Shortage of personnel remains a critical problem throughout all relevant stakeholder groups. This is an urgent problem that needs to be addressed. It is important to ensure there is interest among job seekers in working in the refrigeration business. Currently, refrigeration is a rather slowly progressing field that for this reason tends to receive little attention in higher education, where the focus is mostly laid on high tech, fast-moving fields. All the while, higher education institutions play an important role in sustainable innovation, and it is desirable to have them put focus on the field of industrial refrigeration. Education institutions should educate students about the relevance and importance of innovation in the refrigeration businesses. Not only the technical aspect is important to be developed further, but also the managerial side is crucial. New concepts like shared refrigeration could be greatly beneficial in reducing the environmental impact of refrigeration. Interestingly, students could play a useful role in developing shared refrigeration, as they can perform explorative scans and business case analyses to assess financial and sustainable advantages during internships. Less funds are required for these business case analyses when done by a student than when done by a professional consultancy firm or full-time employees. In short, involving students in the field seems to have the benefit of being able to hit multiple targets in one blow.

Lastly, it is recommended that in all these efforts, attention should not only be laid on the concept of shared refrigeration. This is only one of a myriad of opportunities that lie ahead for industrial refrigeration. As the global demand for space cooling is rising to spectacular numbers, all sustainability-increasing innovations are more than welcome. It might well be possible that other concepts will result in more environmental gain, and those too should be explored. Perhaps the most important recommendation made in this chapter is to significantly increase the amount of innovation that is taking place in the field of industrial refrigeration. Too little attention is given to the topic, while much is to be gained.

8.3 Study programme recommendations

The study programme of Management of Technology offered by Delft University of Technology aims to educate students as “technology managers, analysts of technological markets (either as scientists or consultants), and entrepreneurs in highly technology-based, internationally-oriented and competitive environments for a variety of industrial sectors” (TU Delft, n.d.-b). During the programme, students follow courses that touch upon a broad range of subjects. Several of these courses that are of interest for the subject of industrial refrigeration are Technology, Strategy and

Entrepreneurship, Inter- and Intra-organizational Decision-making, and the Integration Moment in the first year, and Sustainable Innovation and Transitions in the second year. These courses teach students about strategy, decision making, and the dynamics of sustainable innovation. Combining the knowledge from these courses can provide students with the necessary insights to investigate sustainable opportunities that can be useful to achieve a better future, while taking an approach that is welcomed by entrepreneurs, rather than seen as an attack on their freedom.

A point of interest is that the focus in the MOT programme courses now mainly tends to lie either on achieving financial success, or achieving sustainable successes. A combination of these two approaches could be given more attention. A course about shared innovation or strategic sustainable partnerships, like industrial symbiosis and utility sharing, could be added to the programme. While such initiatives were now only briefly touched upon in different courses, a dedicated course was not included in the MOT programme. All the while, I feel that this is an extremely important subject that will be highly relevant for MOT graduates in the future.

Something that could also be improved in the programme is increasing the engagement of students in real-world problems, for example by collaborating with businesses that have practical management problems that need solving. During my specialization, I followed a management design course which was combinedly organized by the faculty of TPM and the Industrial Design faculty. During the course, students were asked to solve real-world problems encountered by actual businesses. These businesses were actively involved in the project, and we had weekly meetings with our company’s management board. This was an incredibly useful experience that I would have liked to have had in more courses.

While during the course Integration Moment, we were also given a real-world problem encountered by a company, this course was far less interactive. There was not a single moment of direct interaction between us and the company we did the project for, and our group’s supervisor turned out to be extraordinarily unhelpful, not providing the guidance we were asking for. The large amount of unclarities we were left to deal with in combination with the large number of students who had to cooperate on one single report, this resulted in a sloppy and incoherent result of which no-one was proud. We all felt that we could have reached a far better result if we had been offered more interaction opportunities with our company, if we had received better guidance, and if the group size would have been smaller. This was the case for the course organized by the faculty of Industrial Design. In short, more practical projects should be included, but care must be taken to ensure a proper execution.

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Appendix A - Participant invitation

Dear [name],

My name is Willem-Jon Littel, master student of Management of Technology at TU Delft. I am currently working on my graduation research, and I would hereby like to invite you to participate in my study.

My research concerns opportunities and possibilities of shared refrigeration systems in Dutch industrial parks. Currently, many companies have their own refrigeration installations - so the situation is fragmented, which results in several disadvantages in both environmental and financial terms. My research relates to the possibility of realizing one central refrigeration installation on an industrial site, from which individual companies can extract cold via a piping infrastructure. Centralizing the refrigeration technology probably has energetic advantages and could fit in well with the current trends of sustainability and greenification. I have attached a short presentation to this email in which I further explain the concept.

Of course, it is not easy to implement such a concept. That is why in my research I am focusing on factors that influence a potential implementation of a shared refrigeration system. Think, for example, of the financial climate, the situation with regard to government policy, but also the willingness of potential partners to participate in the concept, and so on. The aim of my research is to discover which factors form barriers to the implementation of shared refrigeration systems, and how these barriers could be overcome.

In order to get a good idea of the current context and possible obstacles, I am conducting a series of interviews with various parties who have a relevant position and/or expertise. I found your name through … and would like to invite you for an interview. The interview will last approximately 45 minutes and will be recorded. Personal data will of course be treated confidentially and all results will be anonymised.

Please let me know if you are interested in participating. It would help me and my research a lot!

Yours sincerely,

Willem-Jon Littel

(Master's student at the Faculty of Technology, Policy and Management, TU Delft)

Beste [naam],

Mijn naam is Willem-Jon Littel, masterstudent Management of Technology aan de TU Delft. Momenteel ben ik bezig met mijn afstudeeronderzoek, en ik zou u hierbij graag willen uitnodigen hieraan deel te nemen.

Mijn onderzoek gaat over de kansen en mogelijkheden van gedeelde koelvriessystemen op Nederlandse industrieterreinen. Momenteel hebben veel bedrijven hun eigen koel- en vriesinstallaties - er is dus sprake van een gefragmenteerde situatie, die meerdere nadelen tot gevolg heeft op zowel milieutechnisch als financieel gebied. Mijn onderzoek heeft betrekking tot de mogelijkheid om één centrale koelvriesinstallatie op een industrieterrein te realiseren, waar individuele bedrijven via een infrastructuur van leidingen koude van kunnen onttrekken. Het centraliseren van de koelvriestechniek heeft waarschijnlijk energetische voordelen en zou goed kunnen passen in de huidige trends van verduurzaming en vergroening. In de bijlage heb ik een korte presentatie bijgevoegd waarin ik het concept verder uitleg.

Natuurlijk is het niet gemakkelijk om zo'n concept te implementeren. Daarom richt ik mij in mijn onderzoek op factoren die de potentiële implementatie van een gedeeld koelvriessysteem beïnvloeden. Denk bijvoorbeeld aan het financiële klimaat, de situatie wat betreft overheidsbeleid, maar ook de bereidheid vanuit potentiële partners om aan het concept deel te nemen, enzovoort. Het doel van mijn onderzoek is te ontdekken welke factoren obstakels vormen voor de implementatie van gedeelde koelvriessystemen, en hoe de obstakels zouden kunnen worden overkomen.

Om een goed beeld te krijgen van de huidige context en mogelijke belemmeringen voer ik een serie interviews uit met verschillende partijen die een relevante positie en/of expertise hebben. Ik vond uw naam via … en zou u graag willen uitnodigen voor een interview. Het interview zal ongeveer 45 minuten duren en zal worden opgenomen. Persoonlijke gegevens zullen uiteraard vertrouwelijk behandeld worden en alle resultaten zullen worden geanonimiseerd.

Graag hoor ik van u of u geïnteresseerd bent om deel te nemen. Het zou mij en mijn onderzoek erg helpen!

Met vriendelijke groet,

Willem-Jon Littel

(Masterstudent aan de faculteit Techniek, Bestuur en Management, TU Delft)

Appendix B - Consent form

Dear participant, Date:

You are being invited to participate in a research study titled ”Towards shared refrigeration in Dutch industrial parks”. This study is being done by me, Willem-Jon Littel, master student at TU Delft, faculty of Technology, Policy and Management (TPM). The results collected will be used for the master thesis at TU Delft.

The purpose of this research study is to investigate how the implementation of the concept of shared refrigeration in the context of small and medium-sized enterprises in Dutch industrial parks can be facilitated. An important part of this research is identifying the contextual factors, barriers and enablers that surround the new technology in the Dutch context. You have been selected as a relevant party to provide insight into these factors, and I would like to invite you for an interview. This interview will take approximately 1 hour and will be recorded.

The recording and your responses will be kept strictly confidential. Only members of the research team (my supervisors, dr. Jaco Quist and dr. Geerten van de Kaa, and myself) will have access to the information you provide. A summary of the results will be mailed to you after the data is analyzed. The anonymised and aggregated data will be used for the master thesis and will be made publicly available. As of today, there are no known risks associated with this research study. The data protection standards of TU Delft will apply for the secured storage of data. All the personal information collected during the study will be deleted at the end of the project (names, e-mail addresses and telephone numbers that we will have used to contact you). Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any question.

Thank you very much for your time and cooperation. I greatly appreciate the help of your organization and yourself in furthering this research endeavor.

Yours sincerely,
Willem-Jon Littel

Participant signature
I have read and understood the information above, and agree to participate in the research

______________________	____________________	________
[Participant]	Signature	Date

Researcher signature
I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting

______________________	____________________	________
[Researcher]	Signature	Date

If you have any questions or wish to receive more information about the data collected, please contact:
Willem-Jon Littel [phone number] [email address]

Geachte deelnemer, Datum

U wordt uitgenodigd om deel te nemen aan een onderzoek met de titel ”Towards shared refrigeration in Dutch industrial parks”. Dit onderzoek wordt gedaan door mij, Willem-Jon Littel, masterstudent aan de faculteit Techniek, Bestuur en Management (TBM) van de TU Delft. De verzamelde resultaten zullen worden gebruikt voor de masterscriptie aan de TU Delft.

Het doel van dit onderzoek is om te onderzoeken hoe de implementatie van het concept van gedeelde koudetechniek in de context van het midden- en kleinbedrijf op Nederlandse bedrijventerreinen kan worden gefaciliteerd. Een belangrijk onderdeel van dit onderzoek is het identificeren van de contextuele factoren, obstakels en enablers die de nieuwe technologie in de Nederlandse context omringen. U bent geselecteerd als relevante partij om inzicht te geven in deze factoren en ik nodig u dan ook graag uit voor een interview. Dit interview zal ongeveer 1 uur duren en zal worden opgenomen.

De opname en uw antwoorden worden strikt vertrouwelijk behandeld. Alleen leden van het onderzoeksteam (mijn begeleiders, dr. Jaco Quist en dr. Geerten van de Kaa, en ikzelf) hebben toegang tot de door u verstrekte informatie. Een samenvatting van de resultaten zal naar u worden gemaild nadat de gegevens zijn geanalyseerd. De geanonimiseerde en geaggregeerde gegevens worden verwerkt in mijn masterthesis en worden openbaar gemaakt aan het einde van het onderzoek. Op dit moment zijn er geen bekende risico's verbonden aan dit onderzoek. Voor de beveiligde opslag van gegevens zijn de gegevensbeschermingsnormen van de TU Delft van toepassing. Alle persoonlijke informatie die tijdens het onderzoek is verzameld, zal aan het einde van het project verwijderd worden (namen, en e-mailadressen en telefoonnummers die zijn gebruikt om contact met u op te nemen). Uw deelname aan dit onderzoek is geheel vrijwillig en u kunt zich op ieder moment terugtrekken. U bent bij elke vraag vrij om deze niet te beantwoorden.

Hartelijk dank voor uw tijd en medewerking. Ik waardeer de hulp van uw organisatie en uzelf enorm bij het bevorderen van dit onderzoek.

Met vriendelijke groet,
Willem-Jon Littel

Handtekening deelnemer
Ik heb bovenstaande informatie gelezen en begrepen, en ben bereid aan het onderzoek deel te nemen

______________________ ____________________ ________

[Deelnemer] Handtekening Datum

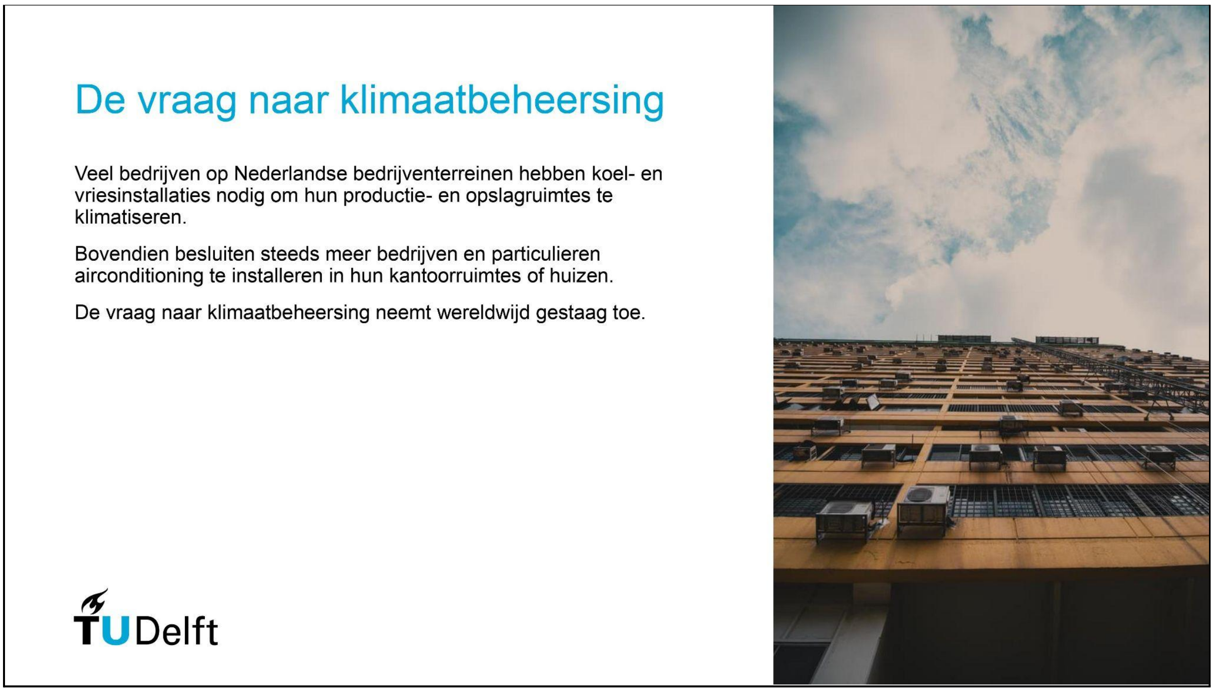
Handtekening onderzoeker
Ik heb bovenstaande informatie duidelijk kenbaar gemaakt aan de deelnemer, en heb zover ik kon kunnen verzekeren dat de deelnemer begrijpt waar toestemming voor wordt verleend

______________________ ____________________ ________

[Onderzoeker] Handtekening Datum

Heeft u vragen of wilt u meer informatie over hoe uw gegevens zullen worden behandeld? Neem contact op:
Willem-Jon Littel [phone number] [email address]

Appendix C - Introductory presentation



Koeling is verantwoordelijk voor 10% van de wereldwijde energieconsumptie.

Het vebruik zal naar verwachting verdrievoudigd zijn in 2050.

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Bron: Eveloy & Ayou (2019)

4

De huidige situatie

Momenteel hebben de meeste bedrijven hun eigen koelvriesinstallaties. Zij delen deze apparatuur meestal niet met andere nabije bedrijven.

Deze fragmentatie leidt tot enkele suboptimale situaties, zoals:

- Slecht of inefficiënt onderhoud
  - Lekkage
  - Hogere energieconsumptie
  - Kortere levensduur
- Moeilijke handhaving van wetten en reguleringen
- Hoge investeringskosten voor de individuele gebruikers
- Restwarmte wordt vaak niet hergebruikt

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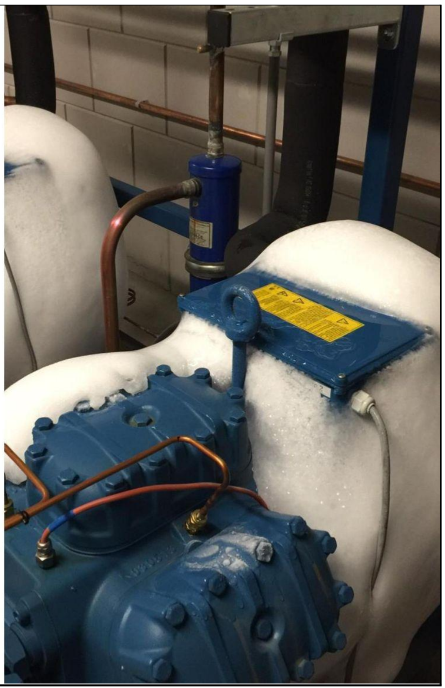

Daarnaast wordt er vooral uit budgetoverwegingen nog vaak gekozen voor installaties met milieuonvriendelijke synthetische koudemiddelen.

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Synthetische en natuurlijke koudemiddelen

Synthetische koudemiddelen zijn schadelijker voor het milieu, omdat ze een sterk broeikaseffect in de atmosfeer veroorzaken.

Ze worden dan ook uitgefaseerd onder het Montrealprotocol.

Natuurlijke koudemiddelen zijn veel duurzamer, maar installaties die ze gebruiken vereisen een hogere initiële investering (tot 40% meer).

Ze zijn echter goedkoper bij hoge capaciteiten en op de lange termijn, omdat ze tot 30% minder energie verbruiken.

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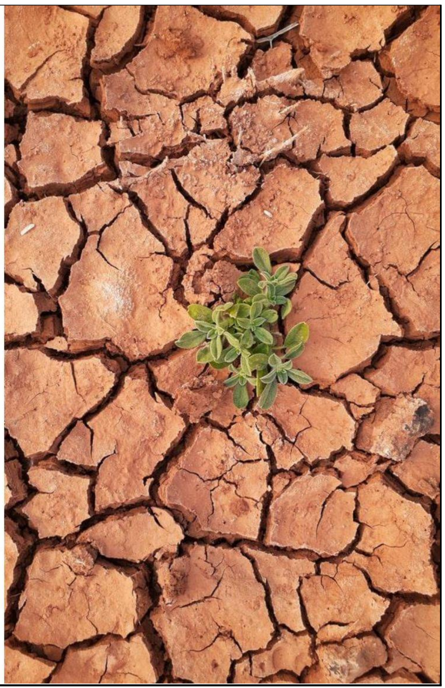

Synthetische en natuurlijke koudemiddelen

Natuurlijke koudemiddelen hebben dus duidelijke voordelen ten opzichte van synthetische koudemiddelen, maar worden toch minder vaak toegepast bij lagere capaciteiten.

Dit geldt vooral voor het midden- en kleinbedrijf, waar men vaak minder investeringsruimte en een relatief kortetermijnvisie heeft.

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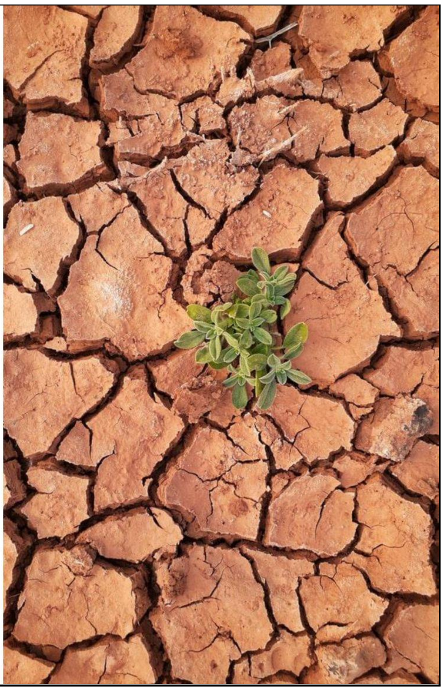

Een oplossing?

Als bedrijven koelvriesapparatuur zouden **delen**, zouden enkele van de nadelen van fragmentatie kunnen worden opgelost:

- Lagere investeringskosten voor individuele gebruikers
  - Natuurlijke koudemiddelen worden interessanter
- Efficiënter in gebruik en onderhoud
  - Minder lekkages
  - Langere levensduur
- Gemakkelijkere handhaving van wetten en reguleringen
- Restwarmte kan gemakkelijker worden hergebruikt

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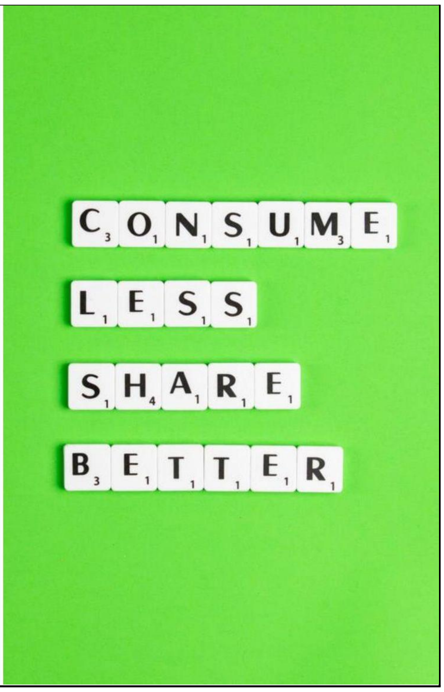
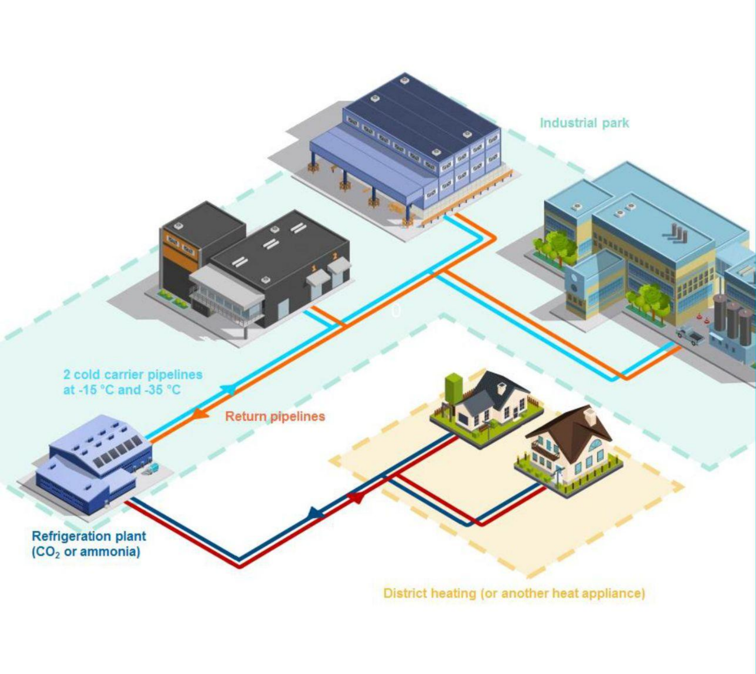
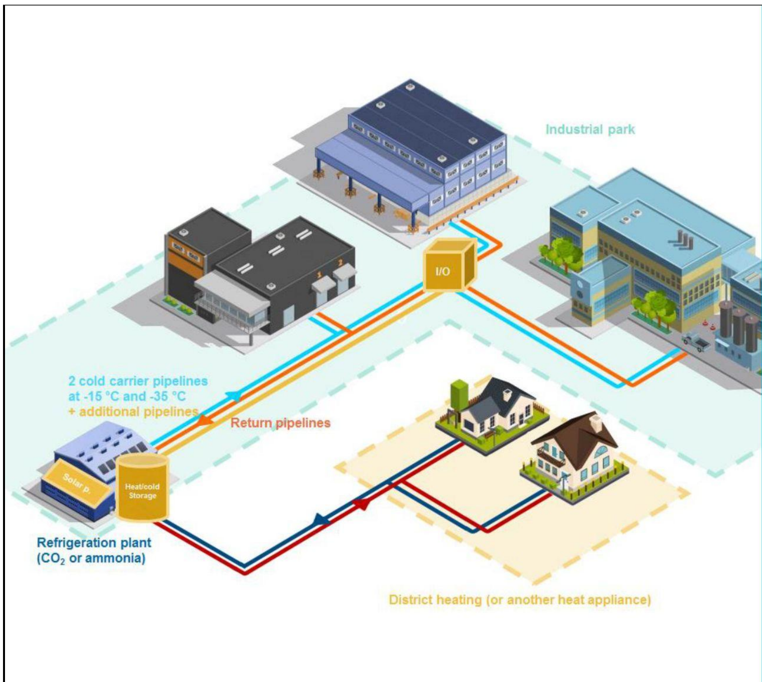




Hoe ziet het concept eruit?

- Een centrale koelvriesplant met een CO_2- of ammoniakinstallatie
- Twee sets pijpleidingen om de koude naar de bedrijven te brengen op twee temperaturen – voor koelen en voor vriezen
- De koude wordt door deze leidingen getransporteerd door middel van een nontoxische, ecologische koudedrager
- Verbruik per bedrijf wordt afgerekend per kWh
- Mogelijkheid tot hergebruik van restwarmte – bijvoorbeeld door koppeling aan stadsverwarming in een nabije woonwijk

10



Optionele elementen

- Warmte/koudeopslag om schommelingen in vraag en aanbod op te vangen
- Pomp- en schakelstations die als I/O-modules kunnen dienen voor bepaalde sectoren
- Een extra set leidingen voor heetgasontdooiing
- Een extra set leidingen voor invriezen op lagere temperatuur
- (Gedeeltelijk) redundante leidingen om eventuele downtime te reduceren
- Zonnepanelen om de plant (gedeeltelijk) van energie te voorzien

11

Om de levensvatbaarheid van zo'n systeem te beoordelen, onderzoek ik factoren die obstakels vormen voor de implementatie, en hoe deze obstakels kunnen worden overkomen.

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Het interview

- Ongeveer 45 minuten
- Wordt opgenomen
- Gegevens worden geanonimiseerd en verwerkt volgens de gegevensbeschermings-normen van de TU Delft
- Deelname is volledig vrijwillig

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15-9-2021 13

Appendix D - 1st round interview questions

Note. As the interviews have been conducted in a semi-structured manner, additional follow-up questions have been asked during the interview itself, which have not been included in this appendix.

Part 1: Introduction participant

1. Can you briefly introduce yourself?
2. How would you describe your position within your organization?
3. How would you describe your organization's role in the business environment?

Part 2: Current and future situation

4. Which problems do you encounter when building refrigeration systems?
5. Which problems do you encounter when maintaining refrigeration systems?
6. How do you envision the future of these installations?

Part 3: Shared refrigeration

7. What do you think are the opportunities and possibilities for shared refrigeration?
8. How do you envision “shared refrigeration in industrial areas”? What elements do you think such a system should consist of?
9. Which of those elements would be absolutely indispensable?
10. Which are optional elements?
11. What do you think are the benefits of shared refrigeration in industrial parks?
12. What do you think are disadvantages of shared refrigeration in industrial parks?

Part 4: Organizational structure and realization

13. How do you envision the organizational structure surrounding shared refrigeration in industrial parks?
14. How do you envision the realization process of shared refrigeration in industrial parks?

Part 5: Economic aspects

15. Could you estimate the costs of shared refrigeration in industrial parks?
16. What do you think would be the financial benefits of shared refrigeration over fragmented systems?
17. What do you think would be the financial disadvantages of shared refrigeration compared to fragmented systems?

Part 6: Environmental aspects

18. What do you think would be the environmental impact of shared refrigeration?

Conclusion

19. Do you have anything to add to this interview?
20. Would you recommend other parties for an interview?

(Dutch)

Deel 1: Introductie deelnemer

1. Kunt u zichzelf kort voorstellen?
2. Hoe zou u uw functie omschrijven?
3. Hoe zou u de rol van uw organisatie in het bedrijfsleven omschrijven?

Deel 2: Huidige en toekomstige situatie

4. Welke problemen komt u tegen bij de nieuwbouw van koelvriesinstallaties?
5. Welke problemen komt u tegen bij het onderhoud van klimaatinstallaties?
6. Hoe ziet u de toekomst van dit soort installaties voor zich?

Deel 3: Gedeelde koeling

7. Wat denkt u dat de kansen en mogelijkheden voor gedeelde koeling zijn?
8. Hoe ziet u “gedeelde koeling op industrieterreinen” voor zich? Uit welke elementen zou zo’n systeem volgens u moeten bestaan?
9. Wat zijn daarvan elementen die absoluut onmisbaar zijn?
10. Wat zijn optionele elementen?
11. Wat zijn volgens u voordelen van gedeelde koeling op industrieterreinen?
12. Wat zijn volgens u nadelen van gedeelde koeling op industrieterreinen?

Deel 4: Organisatiestructuur en realisatie

13. Hoe ziet u de organisatiestructuur rondom gedeelde koeling op industrieterreinen voor zich?
14. Hoe ziet u de realisatie van gedeelde koeling op industrieterreinen voor zich?

Deel 5: Economische aspecten

15. Zou u een schatting kunnen maken van de kosten van gedeelde koeling op industrieterreinen?
16. Wat zouden volgens u de financiële voordelen zijn van gedeelde koeling in vergelijking met gefragmenteerde systemen?
17. Wat zouden volgens u de financiële nadelen zijn van gedeelde koeling in vergelijking met gefragmenteerde systemen?

Deel 6: Milieuaspecten

18. Wat denkt u dat de milieutechnische impact van gedeelde koeling zal zijn?

Afsluiting

19. Heeft u nog iets toe te voegen aan dit interview?
20. Zou u andere partijen aanraden voor een interview?

Appendix E - 2nd round interview questions

Note. As the interviews have been conducted in a semi-structured manner, additional follow-up questions have been asked during the interview itself, which have not been included in this appendix.

Part 1: Introduction participant and actor characteristics

1. Can you briefly introduce yourself?
2. How would you describe your position within your organization?
3. How would you describe your organization's role in the business environment?
4. How would you describe the situation of your organization concerning innovation, collaboration, and sustainability?

Part 2: Open question

5. What are your thoughts about the concept of shared refrigeration in Dutch industrial parks?

Part 3: Actor roles

6. If your organization would participate in a shared refrigeration development initiative, what would be the role of your organization in the process? What role would you see for other parties?

Part 4: Contextual conditions

7. What barriers or enablers for the implementation of shared refrigeration do you see in government policy, laws and regulations? Does the current situation offer opportunities or does something need to change?

8. What barriers or enablers for the implementation of shared refrigeration do you see in the financial climate, subsidies, taxes, grants and other funding opportunities? Does the current situation offer opportunities or does something need to change?

9. Do you think there have been prior collaborations among stakeholders which could enable or counteract a successful implementation of shared refrigeration? Do you think a lack of prior collaborations might form a barrier to successful implementation?

10. What barriers or enablers for the implementation of shared refrigeration do you see in geographical proximity of stakeholders? Does the current situation offer opportunities or does something need to change?

11. What barriers or enablers for the implementation of shared refrigeration do you see in time management? Do you think such a project could be launched at any given time, or should time-related factors be taken into account?

12. What physical and digital infrastructure for interaction between stakeholders do you think is necessary for a successful implementation of shared refrigeration? Do you think this infrastructure is already sufficiently in place or does something need to change?

13. What barriers or enablers for the implementation of shared refrigeration do you see in knowledge exchange between stakeholders (for example concerning what they are doing, what they have to offer, and what they need)? Is there already sufficient exchange of knowledge or does something need to change?

Part 5: Barriers

14. Do you think the following barriers are relevant for the implementation of shared refrigeration? Do you see any other barriers?

Insufficient finances or financial incentives
Insufficient technological knowledge or codification
Inadequate provision of information
Lack of time to invest in IS engagement
Difficulty finding suitable locations for implementation
Lack of commitment by firm leaders
Lack of public awareness and interest
Having a short-term focus
Distrust of potential symbiotic partners
Fear of output quality issues
Fear of not being worth the investment
Lack of cooperation between public and private sector
Others:

Part 6: Conclusion

15. Do you have anything to add to this interview?
16. Would you recommend another party to be interviewed?

(Dutch)

Introductie deelnemer en organisatie

1. Kunt u zichzelf kort voorstellen?
2. Hoe zou u uw functie omschrijven?
3. Hoe zou u de rol van uw bedrijf/instituut in het bedrijfsleven omschrijven?
4. Hoe zou u de situatie van uw organisatie beschrijven wat betreft openheid voor innovatie, samenwerking, duurzaamheid?

Open vraag

5. Wat zijn uw gedachten over het concept van gedeelde koudetechniek op industrieterreinen?

De rol van de organisatie

6. Als uw bedrijf aan gedeelde koudetechniek mee zou werken, wat zou dan de rol van uw organisatie in de implementatie van het concept kunnen zijn? Welke rol ziet u voor andere partijen?

Contextuele voorwaarden

7. Wat voor belemmeringen of bevorderende factoren voor de implementatie van gedeelde koudetechniek ziet u op het gebied van overheidsbeleid, wetten en regelingen? Biedt de huidige situatie mogelijkheden of zal er iets moeten veranderen?

8. Wat voor belemmeringen of bevorderende factoren voor de implementatie van gedeelde koudetechniek ziet u op het gebied van het financiële klimaat, belastingen, subsidies en andere financieringsmogelijkheden? Biedt de huidige situatie mogelijkheden of zal er iets moeten veranderen?

9. Denkt u dat er eerdere samenwerkingen tussen stakeholders zijn geweest die een mogelijke implementatie van gedeelde koudetechniek zouden kunnen bevorderen of belemmeren? Denkt u dat het ontbreken van deze samenwerkingen een belemmering zou kunnen vormen voor een succesvolle implementatie?

10. Wat voor belemmeringen of bevorderende factoren voor de implementatie van gedeelde koudetechniek ziet u op het gebied van geografische nabijheid van stakeholders? Biedt de huidige situatie mogelijkheden of zal er iets moeten veranderen?

11. Wat voor belemmeringen of bevorderende factoren voor de implementatie van gedeelde koudetechniek ziet u op het gebied van tijdsplanning? Denkt u dat zo’n project op elk willekeurig moment kan worden gestart of zijn er timing-gerelateerde factoren waarmee rekening moet worden gehouden?

12. Welke fysieke en digitale infrastructuur voor interactie tussen de stakeholders denkt u dat nodig is voor een succesvolle implementatie van gedeelde koudetechniek? Denkt u dat deze infrastructuur al voldoende aanwezig is of zal er iets moeten veranderen?

13. Wat voor belemmeringen of bevorderende factoren voor de implementatie van gedeelde koudetechniek ziet u op het gebied van kennisuitwisseling tussen partijen (bijvoorbeeld aangaande wat andere partijen precies doen, wat ze te bieden hebben, en wat ze nodig hebben)? Vindt er al voldoende kennisuitwisseling plaats of zal er iets moeten veranderen?

Barriers

14. Denkt u dat de volgende obstakels relevant zijn voor de implementatie van gedeelde koudetechniek op Nederlandse bedrijventerreinen? Ziet u nog andere obstakels?

Onvoldoende financiën of financiële drijfveren
Onvoldoende technische kennis of standaardisatie
Inadequate informatievoorziening
Onvoldoende tijd om te besteden aan innovatieve en duurzame samenwerkingen
Moeite met het vinden van geschikte toepassingslocaties
Gebrek aan toewijding van bedrijfsleiders
Gebrek aan publieke bewustwording en interesse
Het hebben van een kortetermijnvisie
Wantrouwen van potentiële samenwerkingspartners
Angst voor kwaliteitsproblemen in de productie
Angst voor het “de investering niet waard zijn”
Gebrek aan samenwerking tussen de publieke en private sector
Andere:

Afsluiting

15. Heeft u nog iets toe te voegen aan dit interview?
16. Zou u andere partijen aanraden voor een interview?

Appendix F - Results of first interview round

In order to analyze the results of the interviews of the first round, a set of code labels divided over six code groups was created to structure the interview data. In Table F-1, an overview of these code labels can be found together with a description. After the interviews were analyzed using these codes, the statements made by the participants were grouped under more specific labels in an iteration step. This additional sub-level of codes serves in order to allow for more accurate analysis and synthesis. A full overview containing these sub-codes can be found in Table F-2.

Table F-1. Code list for the first interview round.

Code group	Code	Description
Actor characteristics	Customer characteristic	Participant refers to a characteristic of their customers (the consumers of cold energy)
	Government characteristic	Participant refers to a characteristic of the government
	Participant organizational characteristic	Participant refers to a characteristic of their own organization
Current problems	Pre-construction problem	Participant refers to a problem that is typically encountered before construction of refrigeration equipment has commenced (e.g. during the planning phase)
	Construction problem	Participant refers to a problem that is typically encountered during construction of refrigeration equipment
	Post-construction problem	Participant refers to a problem that is typically encountered after the construction of refrigeration equipment has been completed (e.g. maintenance problems)
Current situation	Technical situation description	Participant describes an aspect of the current state of refrigeration technology
	Market situation description	Participant describes an aspect of the current state of the market for refrigeration equipment
	Regulatory situation description	Participant describes an aspect of the current state of the laws and regulations for refrigeration equipment
	Environmental situation description	Participant describes an aspect of the current state of refrigeration equipment in terms of their effect on the environment
Future expectations	Technical expectation	Participant expresses an expectation about the technical state of refrigeration technology in the future
	Market expectation	Participant expresses an expectation about the market for refrigeration equipment in the future
	Regulatory expectation	Participant expresses an expectation about future laws and regulations surrounding refrigeration equipment
	Utility sharing/IS role expectation	Participant expresses an expectation about the role of utility sharing and/or industrial symbiosis in the future
Shared refrigeration vision	Advantage	Participant expresses what (s)he thinks would be an advantage of shared refrigeration
	Risk	Participant expresses what (s)he thinks would be a potential risk posed by shared refrigeration

	Barrier/challenge	Participant expresses what (s)he thinks would be a barrier or challenge to shared refrigeration
	Necessary element	Participant expresses what (s)he thinks would be a necessary element of a shared refrigeration system
	Optional element	Participant expresses what (s)he thinks would be an optional element of a shared refrigeration system
	Financial/organizational aspect	Participant expresses what (s)he thinks would be financial and/or organizational aspects of a shared refrigeration system
	Technical aspect	Participant expresses what (s)he thinks would be a technical aspect of a shared refrigeration system
	Actor/stakeholder involved	Participant expresses what (s)he thinks would be an actor and/or stakeholder involved in any phase of the shared refrigeration development and operation process
	Opinion about shared refrigeration	Participant expresses his or her opinion about shared refrigeration
Other	Illustrative example	The participant illustrates his or her statements with an example

Table F-2. Code list for the first interview round including sub-codes.

Code group	**Code**	**Result**	**Mentioned by**
Actor characteristics	Customer characteristic	Customers are budget-oriented	3
		Customers have a lack of knowledge	2
		Customers are ignorant towards maintenance	2
		Customers are willing to improve sustainability but only if it is financially attractive	2
		Customers focus on the short term	2
		Customers are open for discussion	1
		Customers are not used to price level	1
		Customers tend to be more knowledgeable if the equipment they own is large	1
		Customers want longer warranty for larger installations	1
		Customers want to improve sustainability	1
		Customers tend to be more cooperative if they are the business owner	1
		Customers tend to see the importance of maintenance more if refrigeration is a priority for their business	1
	Government characteristic	Governments have the power to steer the industry towards sustainability	1
		Governments are willing to subsidize sustainable initiatives	1
	Participant organizational characteristic	Installation companies are problem-solving	2
		Installation companies are ambitious	2
		Personnel has a lack of knowledge	1
		Personnel is scarce	1

Current problems	Construction problem	Some installation companies deliver low-quality equipment	1
	Maintenance problem	Poorly maintained installations are common	3
		Customers do not fully understand the value of maintenance	2
		Installation personnel has insufficient knowledge about new technologies	2
		Customers tend to cut in maintenance costs, resulting in lower quality of equipment	1
		Equipment is often not constructed with service-friendliness in mind	1
		Equipment is sometimes installed with insufficient care, resulting in inadequate performance	1
		Rapid change of regulations regarding refrigerants is a challenge for maintenance	1
	Pre-construction problem	Customers do not know what they want	1
		Customers make budget-related choices that result in lower quality of the product	1
Current situation	Environmental situation description	NH3 installations pose a health risk if there is leakage	1
		Synthetic refrigerants are bad for the environment	1
		The sustainability of synthetic refrigerants is being improved	1
		Leakage of harmful refrigerants is common	1
		Natural refrigerant installations are energy-efficient	1
	Market situation description	For small to medium-sized installations, natural refrigerants are still financially unattractive	3
		For large or very small installations, natural refrigerants are already the refrigerants of choice	1
		Refrigeration installations require a large initial investment that does not directly lead to profit returns	1
		There is a shortage of good industrial park areas	1
		The refrigeration market is a remarkably slow-changing one	1
		Heat regeneration is a hot topic	1
		Natural refrigerant installations are offered, but customer go to competitors who offer cheaper synthetic installations	1
		There is a trend of customers moving to natural refrigerants	1
		Customers are advised to opt for natural refrigerants	1
	Regulatory situation description	Government legislation helps upholding the quality of equipment	2
		Synthetic refrigerants are being phased out	2
		Government legislation is a powerful instrument to steer customers in the right direction	2
		Leak detection systems are mandatory for CO2 and NH3 installations	1
		A quotum imposed on synthetic refrigerants leads to scarcity	1
		There are subsidies for installations with natural refrigerants	1
	Technical situation description	The large majority of industrial refrigeration equipment is based on the vapor-compression principle	2
		Leak detection systems are mandatory for CO2 and NH3 installations	1
		Small refrigerators for home appliances are already based on natural	1

		refrigerants	
		Large industrial refrigeration equipment is usually based on natural refrigerants	1
		There are still many installations that run on unsustainable refrigerants	1
		CO_2 and NH_3 installations are energy-efficient	1
		Development of synthetic refrigerants is such that their GWP comes closer to natural refrigerants	1
		Sorption refrigeration equipment is uncommon	1
Future expectations	Market expectation	Natural refrigerants are becoming more attractive	3
		Synthetic refrigerants are becoming more scarce and expensive	2
		The phasing-out of synthetic refrigerants will result in much work for installation companies	1
		Personnel shortages will be a critical problem	1
	Regulatory expectation	Synthetic refrigerants will be completely phased out by 2030 (except in regenerated form)	2
	Technical expectation	There are no important technical developments on the system level	1
		There is development going on in the field of natural refrigerants	1
	Utility sharing/IS role expectation	Sharing refrigeration equipment is possible	3
		Utility sharing and industrial symbiosis are the future	2
		Sharing refrigeration equipment is challenging to realize	2
		Entrepreneurs will be attracted to cooperation if it lowers their refrigeration investment costs	1
		There will be an increase in industrial symbiosis initiatives	1
Shared refrigeration vision	Actor/ stakeholder involved	National government	2
		Energy companies	2
		Land owner	1
		Municipal governments	1
		Contractors and/or installation companies forming a building consortium	1
		Component suppliers	1
		Potential customers	1
		Business associations	1
	Advantage	Shared refrigeration will lead to lower initial investment costs for customers	3
		Shared refrigeration will make maintenance more efficient, resulting in less problems	3
		Shared refrigeration has environmental advantages compared to the current situation	3
		Shared refrigeration will allow for easier waste heat reusal	2
		Shared refrigeration will lead to an increase of equipment life expectancy	2
		Shared refrigeration equipment can be coupled to the power grid more efficiently	2
		Shared refrigeration is an opportunity to accelerate the shift to natural refrigerants	2

		Shared refrigeration will lead to higher quality and reliability of the equipment	1
		Shared refrigeration will allow for a higher degree of government control, increasing sustainability	1
		Shared refrigeration will make enforcement of laws and regulations easier, making defects and fraud less likely	1
		Shared refrigeration will lead to less noise pollution	1
		Shared refrigeration has energetic advantages due to the simultaneity factor	1
		Shared refrigeration offers financial benefits relating to procurement	1
		Shared refrigeration requires less space at the customer's company	1
		Shared refrigeration will result in lower disposal rates of components as they will be repaired more than replaced due to their size and nature	1
	Barrier/challenge	Customer loses control over the equipment	3
		Large investment is required for the shared equipment and infrastructure	3
		Infrastructure design and construction is a challenge	2
		Calculating costs and benefits will be a challenge, making it difficult to assess the economic advantage	2
		Agreements and contracts will be challenging to arrange (e.g. what will be the rules, who is responsible?)	2
		The demand for cold and the demand for heat might not be equal at a given time, making the need for heat storage inevitable	2
		A shared system will require large amounts of refrigerant*	1
		Sudden changes in demand may result in underperformance, challenging the delivery promise	1
		Installation companies might not want to cooperate as a shared system will entail a competitive risk	1
		Cooperation between installation companies might be difficult due to differences in business strategy	1
		The system should be designed in such a way that maintenance or defects affect as few companies as possible, which is a challenge and increases the costs	1
		There are other ways possible to force companies to switch to natural refrigerants	1
		If companies require lower temperatures, the system is not able to provide it	1
		The long pipelines that are required to distribute the cold will cause losses due to friction	1
		There might be a lack of properly trained construction and maintenance personnel	1
	Financial and organizational aspect	Estimations of cooling demand should be made in advance, in collaboration with the consumers	3
		Consumers will pay per kW used	2
		Governments should select suitable application locations	2
		A maintenance team will be closely monitoring and maintaining the	2

		equipment	
		The concept will only be feasible for newly built industrial parks	2
		The initial investment will be significantly lower for the consumer, if only the internal equipment is taken into account	1
		Combined cold and heat generation will allow for higher financial returns	1
		Financial instruments such as deposits and refunds can be applied	1
		Governments will likely be interested and might provide subsidies	1
		Governments should oblige consumers to get their cold energy from the shared refrigeration grid	1
		Possibilities of waste heat reusal should be explored before deciding on a location	1
		Consumers will be responsible for the equipment inside their company	1
		Energy companies have the necessary experience and resources to play an important part in the development of shared refrigeration systems	1
		Shared refrigeration initiatives should be organized bottom-up, as it will create more trust among stakeholders	1
		Possibilities for network enlargement should be created to be able to extend the network in the future	1
		The shared equipment should be strategically positioned to prevent noise pollution as much as possible	1
		A simultaneity factor should be taken into account in the capacity calculations	1
		The terms and conditions should be communicated to the potential partners early in the process	1
		Responsibilities must be clearly defined	1
	Necessary element	Piping infrastructure (two ways)	3
		Pumps	2
		Compressor sets	2
		Cold generator (separator vessels)	2
		Heat exchanger (gas coolers)	2
		The system should be doubled allowing for the generation and distribution of two temperatures: -15 and -35	2
		Switchboards	2
		Equipment to measure the cold use of consumers (based on temperature and flow)	2
		Leak detection equipment	2
		Easily reachable safety/maintenance valves	2
		Heat storage system	2
		Communication cables for safety system	1
	Opinion about shared refrigeration	Shared refrigeration is a viable concept	2
		Shared refrigeration has advantages over the current situation	2
		Shared refrigeration is complicated to realize	2
		The technical challenges are resolvable	1

		It is weird that shared refrigeration has not been applied	1
		Consumers will be interested in participating in shared refrigeration initiatives	1
		There are possible alternatives that might result in the same environmental gains	1
	Optional element	Intermediate pumping/switching stations (I/O modules)	2
		Heat recovery system	1
		Hot gas defrosting system	1
		Redundant infrastructure	1
		A third machine and infrastructure for lower temperatures	1
		Solar panels to power the equipment	1
	Risk	There is a risk of leakage of the infrastructure	1
		There are serious safety aspects to natural refrigerants	1
		The network may be disturbed by sudden changes in demand, which may result in underperformance	1
		Malfunction of a shared refrigeration system affects many companies, possibly resulting in claims etc.	1
		Shared refrigeration might offer a competitive risk for installations companies	1
	Technical aspect	Losses due to friction should be taken into account	3
		High quality isolation should be applied	2
		Capacity used by consumers will be measured with flow meters and temperature meters	2
		A CO2 pump system is the best option to apply*	1
		NH3 installations pose serious risks and are therefore no viable option*	1
		There will be a secondary transmission fluid (Thermera)	1
		The primary refrigerant (CO2) will be distributed over the whole industrial area	1
		A hot gas defrosting system will save much energy, up to 10 kW	1
		The compressor sets will increase or decrease pressurization resulting from a detection of lower pressure. No electrical communication is needed outside the plant	1
		The pipelines will be made of thick-walled stainless steel	1
		The pipelines will have expansion arches to account for temperature-induced expansion	1
		Leakages are more likely to occur at the end user location and the central plant than in the piping	1
		Piping has to be laid sufficiently deep (about 1.5-2 meters under street level)	1
		The system must be designed in such a way that maintenance or defects affect as few companies as possible	1
		If higher temperatures are required by consumers, this will result in a loss of capacity at their end	1
		Thermera is a better option as a secondary refrigerant than glycol	1

Appendix G - Code list second interview round

Table G-1. Code list for the second interview round.

Code	**Code group**
Act_Associations	Actor properties
Act_Business	Actor properties
Act_Consultancy	Actor properties
Act_Public	Actor properties
Act_Research & Ed	Actor properties
Barr_Distrust	Barrier list
Barr_Finances	Barrier list
Barr_Inadequate information	Barrier list
Barr_Lack of commitment	Barrier list
Barr_Lack of cooperation public private	Barrier list
Barr_Lack of time	Barrier list
Barr_Locations	Barrier list
Barr_Not worth investment	Barrier list
Barr_Public awareness	Barrier list
Barr_Quality issues	Barrier list
Barr_Short term focus	Barrier list
Barr_Technology	Barrier list
Cont_Financial climate	Contextual factors
Cont_Geographical prox	Contextual factors
Cont_Knowledge exchange	Contextual factors
Cont_Physical digital infrastructure	Contextual factors
Cont_Policy law regulation	Contextual factors
Cont_Prior collab	Contextual factors
Cont_Timing	Contextual factors
Oth_Activity	Other
Oth_Actor	Other
Oth_MIsc	Other

Refrigeration is an important aspect of the industrial world. As worldwide demand for it is growing while environmental issues are being increasingly addressed by regulations, the call for more sustainable practices in the refrigeration fields becomes louder and louder. Currently, refrigeration systems are mostly fragmented, each business having its own set of equipment. This brings along several drawbacks, such as inadequate maintenance, absence of waste heat reusal, high investment costs, and a tendency of especially SMEs to prefer installations with synthetic refrigerants which are cheaper to acquire, but which are more harmful to the environment in case of leakage, and less efficient in operation. A solution can be sought in “shared refrigeration systems”, a form of utility sharing and industrial symbiosis where a central refrigeration plant distributes cold refrigerant via a network of piping to individual companies. This concept has been poorly explored, and the current research aims to investigate the barriers and enablers that are in place for a potential implementation of this shared refrigeration technology among SMEs in Dutch industrial parks, as well as to investigate how the barriers can be overcome.