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ELECTRIFICATION BLUEPRINT FOR HIC ROTTERDAM – BOTLEK

AN EXPLORATION OF OPPORTUNITIES FOR SYMBIOSIS-BASED ELECTRIFICATION

Rotterdam, May 17, 2023
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CONTENTS

1. INTRODUCTION

Following the formulation of a Climate Agreement on national level, Rotterdam formulated its own Rotterdams Klimaatakkoord (RKA, Rotterdam Climate Agreement) in November 2019 with the goal of cutting carbon emissions by 49% in 2030. Among the 49 climate deals in the RKA, industrial electrification is encompassed in climate deal 5. This climate deal aims to replace natural gas used for heating up to 300°C by electricity as much as possible. E-boilers and heat pumps emerge as important electrification options for the short term (Energieswitch - Rotterdamse Klimaat Alliantie, 2019). However, this means that residual streams currently used for the production of steam, hydrogen and heat (see Figure 1.1) have to be repurposed in order to create a viable business case.

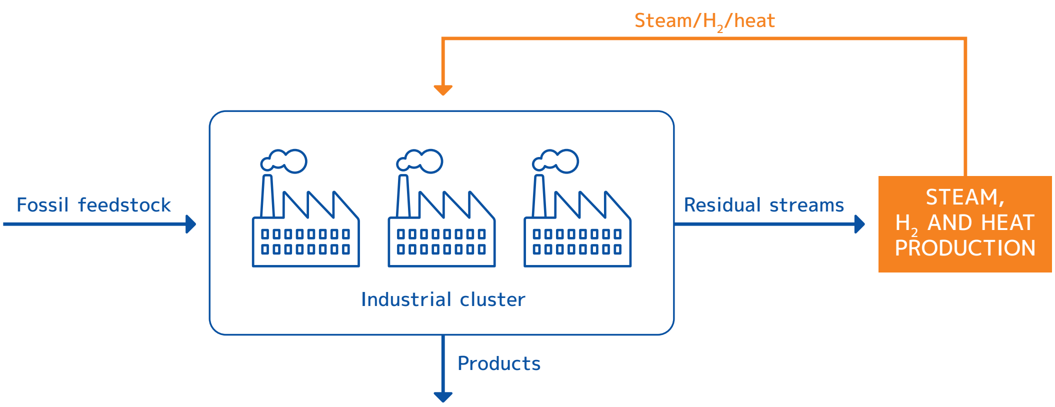

Figure 1.1 - Current situation in many production plants: residual streams (gasses or liquids), by-products from the production process, are used to generate steam, hydrogen and heat.

This study explores the opportunities for implementing cluster-level electrification while repurposing the residual streams currently used for the production of steam, hydrogen or heat, for e.g. methanol or blue hydrogen production. This process, where residual streams of certain production plants become valuable materials for others, is called industrial symbiosis (European Commission, 2018). This concept can also be applied to the joint provision of utilities and different services between the companies in an industrial cluster. A cluster is defined as geographic concentrations of interconnected companies in a particular field, linked by commonalities and complementarities (Porter, 2000).

By taking industrial symbiosis as a starting point for cluster-level electrification, we introduce the concept of **symbiosis-based electrification**. Symbiosis-based electrification focuses on the repurposing of residual streams (gases or liquids). In the current, fossil-based, industry, many residual streams resulting from production processes are used to generate heat and/or steam for those same processes. However, if heat and steam production become (partially) electrified, these residual streams become redundant, having a negative impact on the business case for electrification. By taking an industrial symbiosis perspective, we look at how value could be added to these residual streams in a (partially) electrified industry. In this way, reducing carbon emissions results in an opportunity for the production of additional valuable chemicals.

That being said, the possibilities for the scaling of such production are limited at the level of individual companies. Hence, the business case for employing residual streams for the purpose of producing additional valuable chemicals is not convincing yet. However, considering this repurposing of residual streams at the cluster level creates opportunities for creating a local market and reducing infrastructure and logistics costs. Figure 1.2 highlights the advantages of cluster-level interaction regarding residual streams.

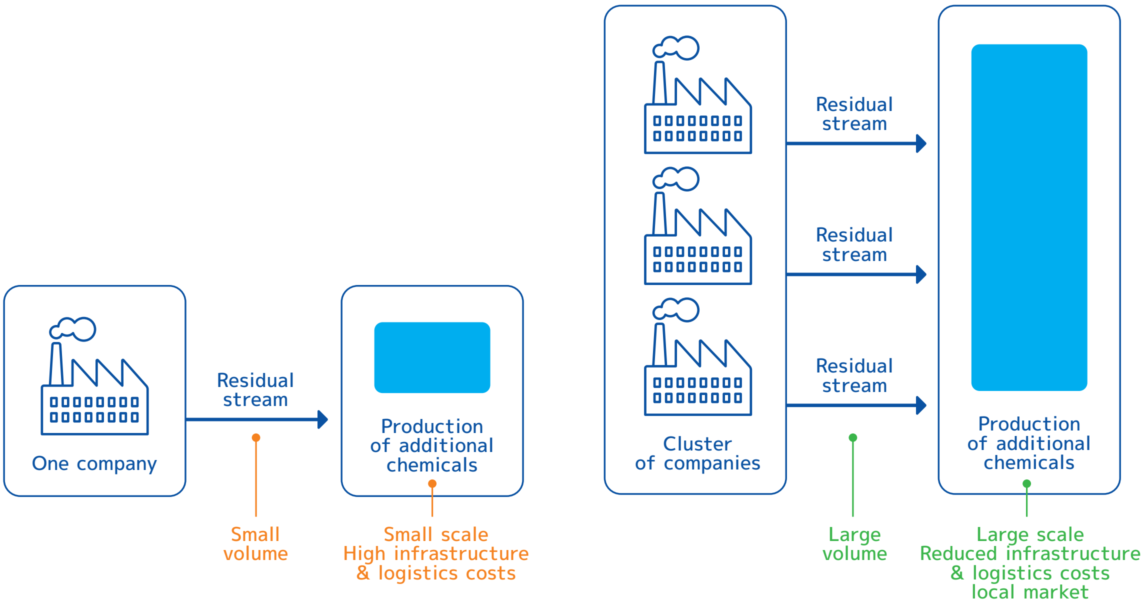

Figure 1.2 - The advantages of repurposing of residual streams for the production of additional valuable chemicals at the cluster level in comparison to an individual company.

To enable the sustainable transformation of the industries in the Port of Rotterdam, the Fieldlab Industrial Electrification (FLIE) was formed in 2021 by five partners: Deltalinqs, FME, TNO, Port of Rotterdam Authority and InnovationQuarter, supported by the Municipality of Rotterdam and the Province of Zuid-Holland.

One of the key features of the FLIE is the Solution Centre, which aims at enabling knowledge transfer, supporting innovation and promoting cooperation between partners in the value chain; this will be done e.g. through (bottom-up/site-specific) feasibility studies and (top-down) strategic studies.

The Electrification Blueprint Botlek study is conducted by the Solution Centre. As this study applies industrial symbiosis to resolve the repurposing of residual streams (gases or liquids), it can be placed between the strategic level and the site-specific level.

Still, such a cluster-level solution comes with a considerable challenge as it requires the cluster to take collective action. It involves redirecting energy and material streams, requiring new or upgraded infrastructure, adequate governance and measures for sharing data securely without disclosing commercially sensitive information. These steps require commitment from the companies, as well as close collaboration between these companies with the Port of Rotterdam Authority, local governments and the grid operator.

The Electrification Blueprint Botlek study aims at gaining insights in the benefits and opportunities for implementing symbiosis-based electrification in the Botlek area of the Port of Rotterdam.

This report is the outcome of an explorative exercise regarding the opportunities and challenges of symbiosis-based electrification in the Botlek area, including possible solutions to break the existing barriers. It collects the insights from phase 1, and serving as input for phase 2, as the Electrification Blueprint Botlek is only a starting point for similar initiatives in areas of the Port of Rotterdam or other industrial clusters. In this report we present the following:

- **Chapter 2** presents the rationale for this study on symbiosis-based electrification. Up to now, little attention has been paid to the intra-company electrification through industrial symbiosis. In this study, the potential exchange of resource streams between companies is taken as a starting point for further industrial electrification.
- As part of this study, we held interviews with companies in the Botlek cluster, designed integrated technology concepts and organized a stakeholder workshop. **Chapter 3** elaborates these steps further.
- **Chapter 4** describes the first part of the study: the techno-economic analysis of integrated technology concepts (ITC's). These ITC's combine collective electrification with a resolution to the repurposing of residual streams. In this chapter, the design of the ITC is outlined along with their performance regarding costs and CO_2 emission reduction.
- **Chapter 5** describes the second part of the study: strategic analysis. In this analysis, opportunities and barriers to symbiosis-based electrification are explored together with stakeholders. Moreover, potential solutions to resolving the identified barriers are suggested and recommendations regarding the set-up of a durable governance in the Botlek area are presented.
- **Chapter 6** proposes several actions to enhance future collaboration among companies in the Botlek cluster with the end goal of enabling large-scale symbiosis-based electrification.

Note from the authors
This report was written in large part before the war in Ukraine. As the war has brought an enormous shock to the energy market and has led to rising energy prices, some statements in this report regarding the energy market or energy prices may be outdated at the time of publishing.

2. RATIONALE FOR A STUDY ON SYMBIOSIS-BASED ELECTRIFICATION

Firstly, This chapter discusses electrification and industrial symbiosis. In the final section, these two concepts are integrated into the concept of **symbiosis-based electrification**.

2.1 ELECTRIFICATION

Electrification from renewables is broadly regarded as an important decarbonization strategy (Johansson, Åhman, & Nilsson, 2018; Chen, Lu, & Banares-Alcantara, 2019; Wiertzema, Svensson, & Harvey, 2020; Bataille, 2020). Indeed, to achieve far-reaching decarbonization, electrification is essential, even if key technologies such as Carbon Capture, Utility & Storage (CCUS) and measures targeting energy efficiency are fully implemented (Johansson, Åhman, & Nilsson, 2018; Bataille, 2020).

Many studies have explored electrification options. A part of these publications are strategic system studies, e.g. the system study for energy infrastructure in the province of Zuid-Holland (TNO, CE Delft, Quintel Intelligence, 2020), the Netherlands' industrial electrification roadmap (Hers, et al., 2021), the Cluster Energy Strategy Rotterdam-Moerdijk (CES Rotterdam-Moerdijk, 2021) and the research performed in 2018-2019 on the development of a robust electricity infrastructure in the Port of Rotterdam (TenneT; Stedin; Port of Rotterdam, 2019).
On the other side of the spectrum, there are site-specific feasibility/business case studies, which are often confidential.

Within the system studies, the aggregated opportunity and boundary conditions for electrification are key elements, such as infrastructure. These studies have shed light on the following generic barriers and challenges for electrification:

1. The current cost structure (including high capacity tariffs) (TNO, CE Delft, Quintel Intelligence, 2020)
2. The intermittency and variability of renewable energy sources, which require improve planning and coordination to balance the demand of supply of electricity (Chen, Lu, & Banares-Alcantara, 2019; Hers, et al., 2021), considerable investments in the grid distribution capacity (Wiertzema, Svensson, & Harvey, 2020) and new flexibility mechanisms (den Ouden, et al., 2018)
3. Space limitations for electrification assets on site and for electricity infrastructure (TNO, CE Delft, Quintel Intelligence, 2020)
4. The availability of renewable electricity (Hers, et al., 2021)
5. Limited grid capacity, which makes grid upgrade necessary (CES Rotterdam-Moerdijk, 2021). However, such changes on the grid feature long lead times (Scholten, 2021)

The site-specific feasibility studies that have been performed show that creating a viable business case for electrification is difficult due to various reasons (FLIE, 2021):

- Difficulty to realize economies-of-scale since individual projects involve additional costs such as grid capacity upgrades.

- Projects work to the advantage of stakeholders (energy providers, grid operators or suppliers) other than the project initiator, e.g. when it comes to economic benefits or CO_2 abatement.
- The overall business case for the site may be negatively impacted by downstream effects arising from the deployment of electrification. For example, in many processes. (Low-cost) residual products or tail gases are used for steam and heat generation. Hence, these products and tail gases need to be repurposed when the generation of heat or steam is electrified.
- Current commercially viable electrification options are only applicable to low temperatures (<200°C). However, in many industries low-temperature heat or steam is largely cascaded from high-temperature processes, such as refining (600°C) and naphtha cracking (850°C). Therefore, electrification in these industries will yield limited CO_2 reduction and cost savings as only low-temperature processes will be affected.

2.2 INDUSTRIAL SYMBIOSIS

"Industrial symbiosis (IS) is a systems approach to a more sustainable and integrated industrial system, which identifies business opportunities that leverage underutilized resources (such as materials, energy, water, capacity, expertise, assets etc.)" (Lombardi & Laybourn, 2012). By considering industrial symbiosis, companies can build on existing opportunities that result from the potential exchange of (residual) energy and material flows. The principle of industrial symbiosis is visualized in Figure 2.1.

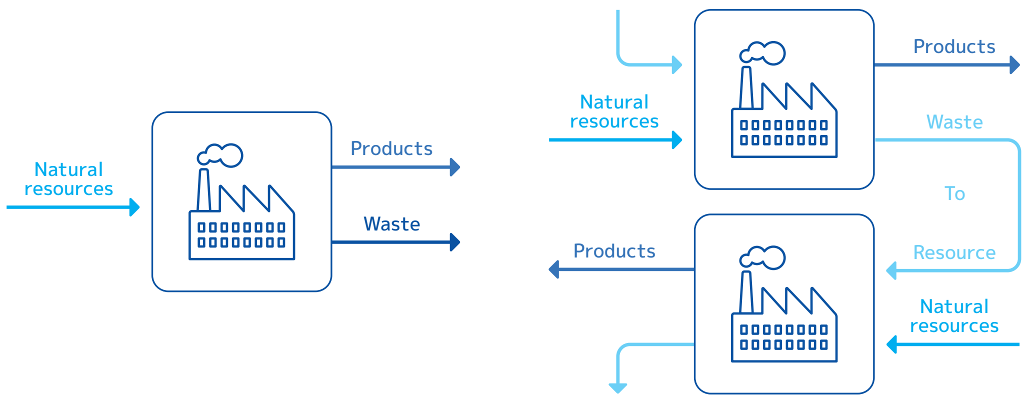

Figure 2.1 - Visualization of the potential of industrial symbiosis.

Within industrial symbiosis, there are three categories of synergies:

1. Substitution synergies: replacing one input flow of one process by the output flow from another process. For example, by-product synergies.
2. Mutualization synergies: in the case of multiple industries using or producing the same type of flow, they consist in mutualizing the supply or treatment of these streams. Such types of exchanges include infrastructure and services sharing.
3. Information sharing: one of the prime requirements to the creation of IS opportunities is the exchange of information between the stakeholders.

Besides environmental and social benefits, industrial symbiosis also has substantial economic benefits. A research by the University College London, the Technopolis Group, Trinomics and TNO has shown that, for European businesses, cost savings due to landfill diversion could reach 72.7 billion euros and additional earnings from selling secondary materials could reach 12.9 billion euros (Domenech, Doranova, Roman, Smith, & Artola, 2020). However, the same study indicates that, as of now, this market potential is underutilized because of several reasons, among others:

- Industrial symbiosis activities do not provide a viable business case yet.
- Access to data about the volumes and characteristics of available secondary resource streams is limited for individual companies.
- There is a lack of capabilities to facilitate the exchange of resources streams, find matching conditions and invest in required logistics and infrastructure arrangements.

2.3 LINKING ELECTRIFICATION AND INDUSTRIAL SYMBIOSIS

Up to now, little attention has been paid to the electrification at the cluster-level through industrial symbiosis. This level of analysis can be positioned between the level of system studies and site-specific studies, see Figure 2.2.

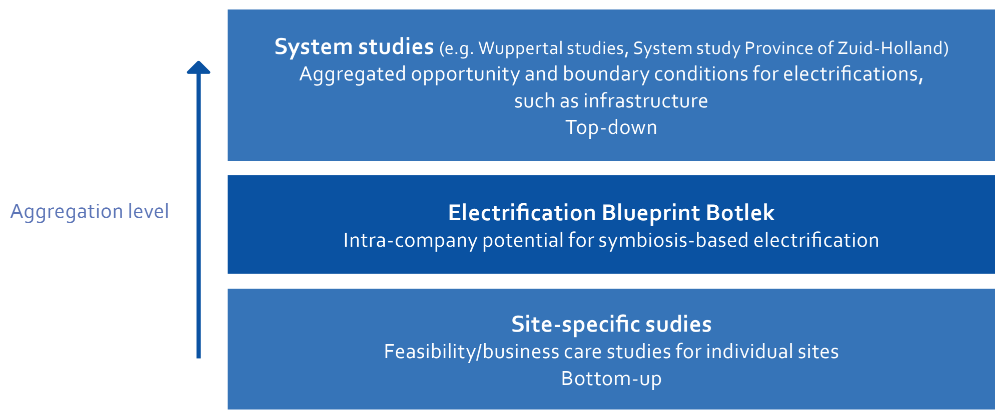

Figure 2.2 - Visualization of the position of the level of analysis of this study relative to system studies on the one hand and site-specific studies on the other hand.

System studies focus on the opportunities and boundary conditions for electrification on a national or regional level. Site-specific feasibility studies are characterized by focusing only on the feasibility of electrification options for a specific company, site or plant.

Focusing on the short-term reduction of CO_2 emissions in light of the Rotterdam Climate Agreement, the Electrification Blueprint Botlek study takes the electrification of heat and steam production as a starting point. As individual companies can reach limited economies-of-scale, the repurposing of residual streams is considered at the cluster level. As such, on-site constraints and infrastructural and logistic challenges can be overcome. Moreover, a local market for additional valuable chemicals is created. These advantages are visualized in Figure 2.3.

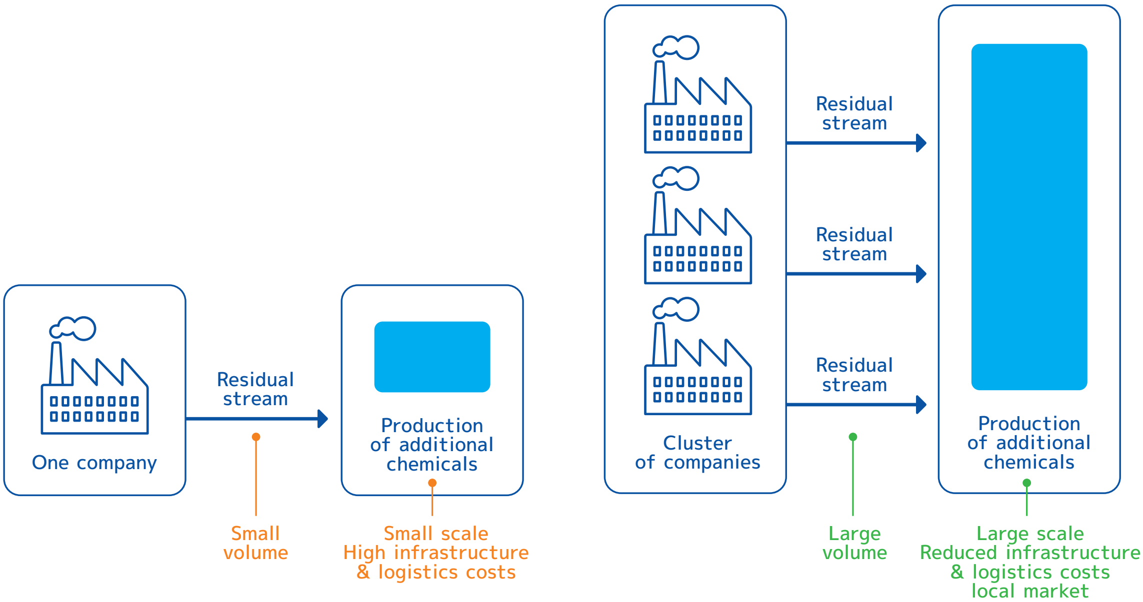

Figure 2.3 - The advantages of repurposing of residual streams for the production of additional valuable chemicals at the cluster level in comparison to an individual company.

The study focuses on connecting the potential demand and supply of resource streams (energy and/or material flows) between companies in the Botlek region, in order to resolve the displacement of residual streams due to electrification. In this way, an important barrier to electrification is reduced.

An important underlying assumption is that the production processes that will generate the aforementioned residual streams will remain in place for the next 20-30 years. This is an important assumption because, if there were a complete technological overhaul of the current production processes, residual streams would change or disappear, reducing the overall need for considering industrial symbiosis. Moreover, the electrification of steam and heat production requires an adequate grid connection capacity on the high-voltage grid.

2.4 THE CASE OF THE BOTLEK INDUSTRIAL CLUSTER (PORT OF ROTTERDAM)

The Rotterdam Climate Agreement (RKA), concluded in November 2019, presents 49 climate deals to deliver a 49% CO_2 emission reduction by 2030 of the Rotterdam-Moerdijk port – industrial region.[1] Climate deal #5 'Industrial Electrification' states the following:

> *"Industrial processes using heat up to 300 °C will be electrified as much as possible, replacing natural gas. Wind-at-sea will supply significant amounts of electricity, which can be absorbed more easily by industry than other parts of the energy system. The backbone for electrification, resulting from this, can also help to balance the system. To stimulate innovations, a field lab will be developed. Furthermore pilot projects are being worked on as well as developing a sustainable back-up boiler for the Botlek steam network."*

In order to achieve defined climate deals, the Municipality of Rotterdam together with the province of Zuid Holland provided strong backing for launching the Fieldlab Industrial Electrification (FLIE) in February 2021. FLIE is an innovation hub, where Power-to-X technologies are identified, developed, tested and prepared for implementation, with the aim to stimulate the decarbonization of energy intensive industry and to promote innovative equipment suppliers within small and medium enterprises.

One of the FLIE goals is to deliver an electrification blueprint for the Harbor Industrial Cluster (HIC) Rotterdam. Clusters are defined as geographic concentrations of interconnected companies in a particular field, linked by commonalities and complementarities (Porter, 2000).

In the following chapters the electrification blueprint will be described based on research in the Botlek area (Figure 2.4), where the intra-company potential for electrification through industrial symbiosis has been the focal point.

Figure 2.4 - Port of Rotterdam and the Botlek area. Source: Port of Rotterdam Authority.

1 in-drie-stappen-naar-een-duurzaam-industriecluster-rotterdam-moerdijk-in-2050.pdf (portofrotterdam.com)

3. OBJECTIVES AND APPROACH OF THE STUDY

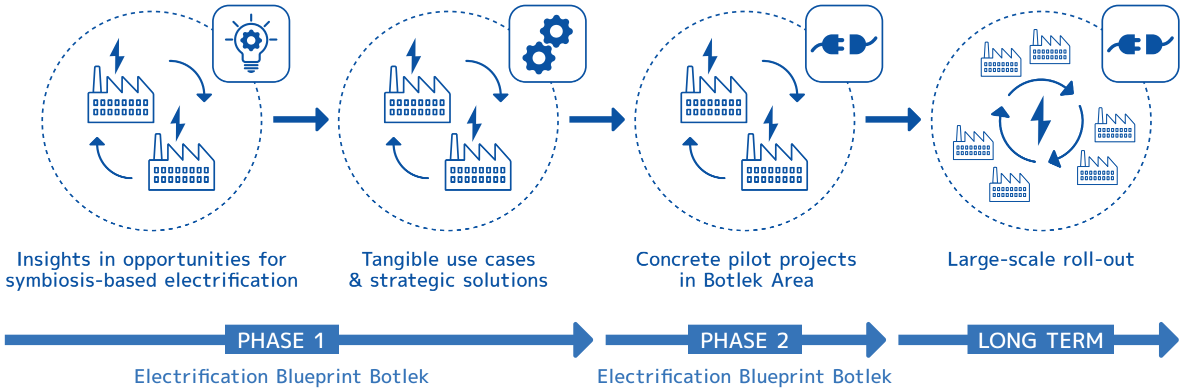

Figure 3.1 - Overview of the objectives of the Electrification Blueprint Botlek study: from exploring opportunities for symbiosis-based electrification to large-scale roll-out in the Botlek and beyond.

As mentioned, the Electrification Blueprint Botlek consists of two phases. These phases and their goals are visualized in Figure 3.1. The goal of phase 1 of the Electrification Blueprint Botlek study is to gain insight of the opportunities for symbiosis-based electrification in the Botlek area. Based on these insights, tangible integrated technology concepts and strategic solutions are developed. These serve as input for the design of concrete pilot projects in the Botlek area (phase 2) and, ultimately, for the large-scale deployment of symbiosis-based electrification in the cluster and beyond.

To achieve the objectives of phase 1, several steps were undertaken. Figure 3.2, shows a the step-wise approach considered in this study, including the methods used for each step.

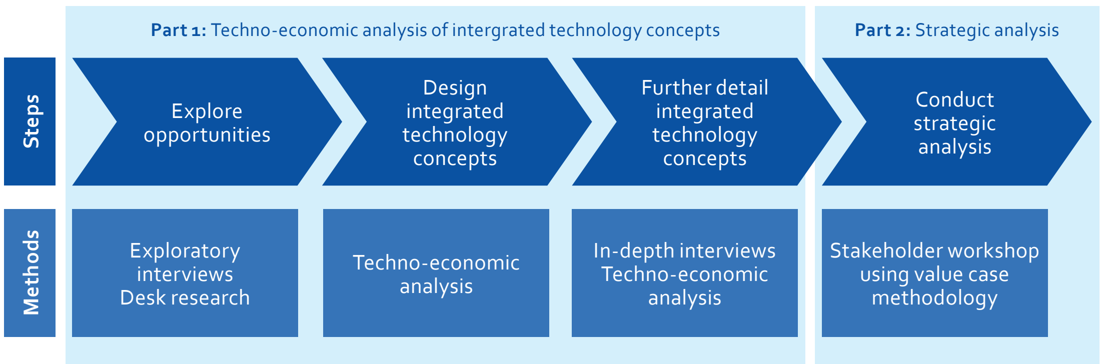

Figure 3.2 - Overview of the approach used in Electrification Blueprint Botlek phase 1. The top row shows the steps undertaken in the project and the bottom row shows the methods applied in each step.

In order to build a value network together with the companies involved in step 4, integrated technology concepts were designed. To define these integrated technology concepts, information from companies with regards to energy and material streams is necessary.

Therefore, a first round of interviews was held to explore opportunities and gain high-level information that served as input for the techno-economic analysis underlying the integrated technology concepts. Through a second round of in-depth interviews the design of integrated technology concepts was further detailed.

1. **Explore opportunities.** The Botlek area seems to be a cluster with promising potential for industrial symbiosis, as it houses many chemical and petrochemical companies, and it forms a hub for many supraregional economic activities with hinterland connections via rail, road and water. The project team started by listing all companies located in this area, next to several stakeholders which are closely involved by the activities that take place.

   Using PBL data on residual streams, asset specifications and energy and material flows in the cluster, the technical team identified the main electrification options which could meet the cluster's steam and low temperature heat demand. This served as a first input to initiate contact with the companies located in the Botlek area.

   Eleven companies showed their interest and where interviewed in a first exploratory discussion. During these interviews, the companies provided feedback on the electrification options identified. Based on the companies' feedback, three integrated technology concepts were formed. We then held a second interview round with the companies where we had in-depth discussions about topics like:

   Besides questions related to the site's current situation, there were discussions related to future measures, such as:
   - Individual companies' views on possible collaboration with other partners in the cluster
   - Characterization of CO_2 streams
   - Which energy carriers companies expect to increase in the future (electricity, natural gas, biomass and hydrogen)
   - The usage of oxygen in their processes (valorization for O_2 from electrolysers).

2. **Design integrated technology concepts.** The feedback on the electrification options identified served as additional valuable input for our technical sub team to design tangible integrated technology concepts for symbiosis-based electrification using a techno-economic analysis. For an overview of the integrated technology concept design, see Chapter 6.

3. **Further detail integrated technology concepts.** An additional second interview round with the aim to improve the pre-assessed designs.

4. **Conduct strategic analysis.** A stakeholder workshop based on the Value Case Methodology (VCM) of TNO was organized, with the aim to focus on the strategies to enhance the industrial symbiosis in this cluster. With VCM, stakeholder values can be mapped in a comprehensive, independent and objective manner. This mapping can then be used for aligning their objectives. As such, VCM allows for broad support for an investment decision in a joint project and achieving collective action. VCM has four steps: design, quantification, valuation and alignment (for more information see next paragraph).

In this study, the first step of the VCM (design) was applied, which focuses on creating clarity in a structured qualitative way about the investment decision and the different options available, the expected roles of each stakeholder and the stakeholders' individual objectives. To do so, the Value Network Canvas, one of the tools within the VCM, was used. With this canvas, a value network as illustrated in Figure 3.3 can be sketched.

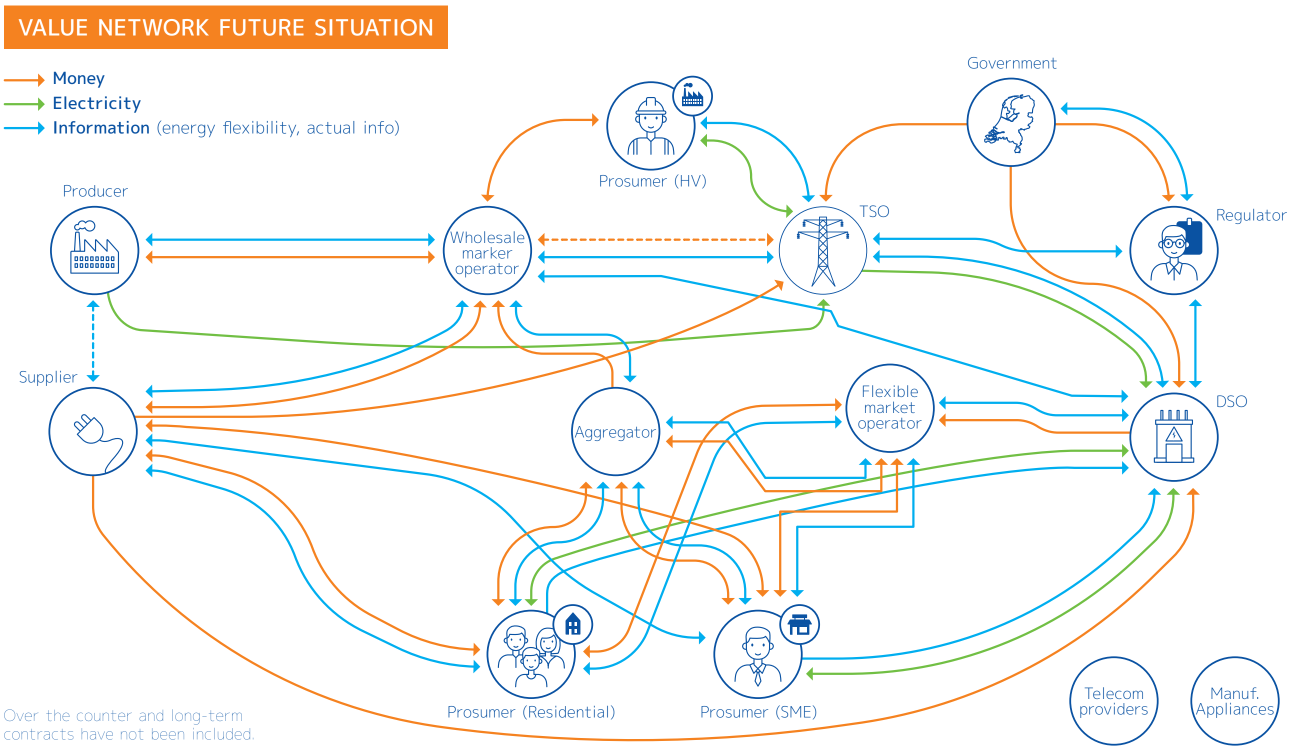

Figure 3.3 - Example of a value network. Source: (Berkers, 2020)

The first step in the workshop was to sketch a design and form a common vision. Secondly, Botlek area companies and stakeholders participated in a two-phased value network game. In phase one, two groups were formed and each had to map and describe the value network for a concrete industrial symbiosis integrated technology concept. This entailed describing the roles that were relevant and the reciprocal needs. For this purpose, the template shown in Figure 3.4 was used. In the central space, the participants could draw the envisioned value network. Then, on the bottom, aspects related to different categories (Technology, Business Case, Data, Infrastructure, Governance, Policy & Other) could be described. These could be needs (e.g. "for this value network to be realized we need a Data Safehouse") or challenges and barriers to be overcome. The cards shown in Figure 3.5 were used for the actors in the value network.

In phase two, the groups evaluated each other's value network based on a number of evaluation criteria (see Figure 3.6). The workshop was concluded by collecting individual needs to further design the cluster collaboration, based on the barriers and challenges to overcome to realize the value networks sketched in phase 1.

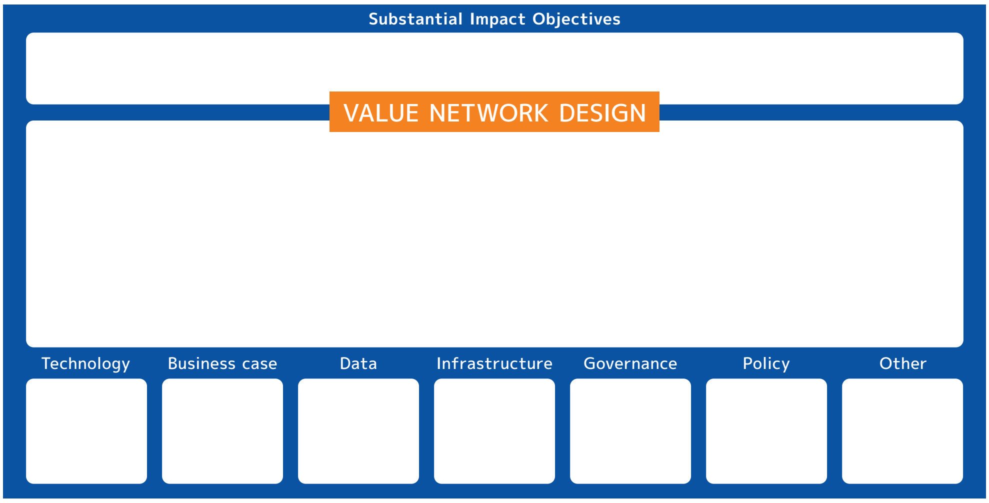

Figure 3.4 - Value network design template.

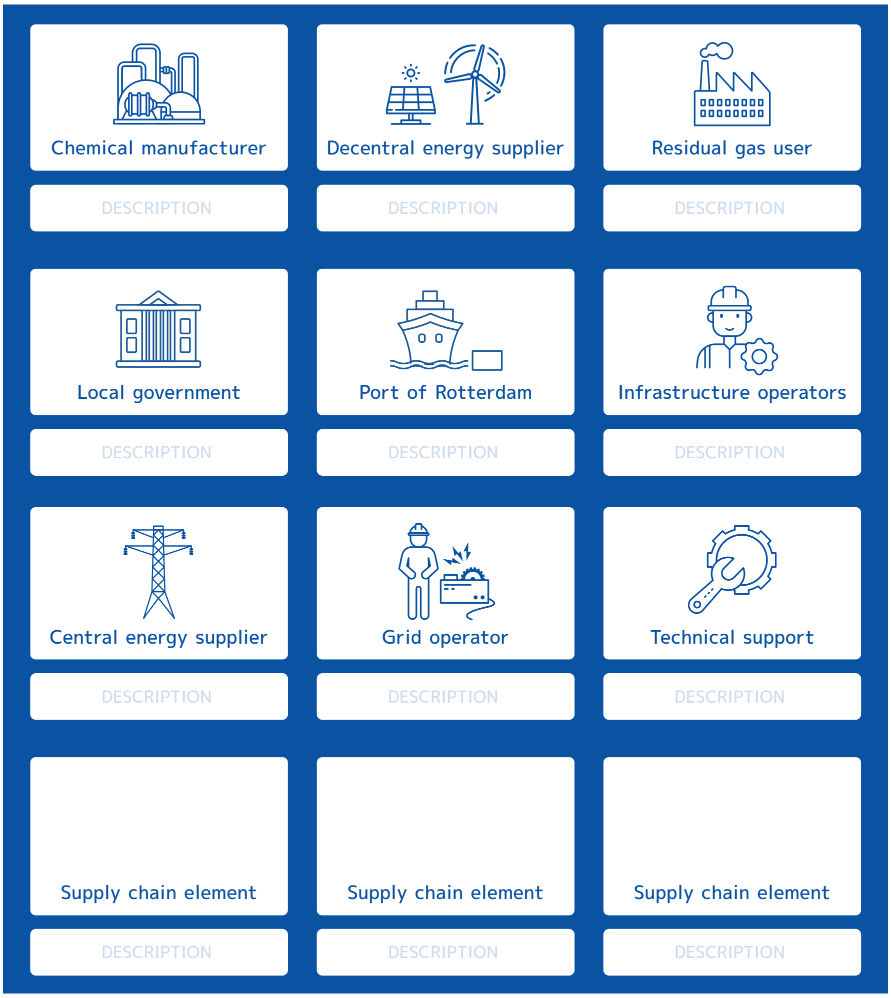

Figure 3.5 - Example of stakeholders to be included in the value network.

ASSESS

TECHNOLOGY

- New technologies have potential to create economic and societal value, but only work in a wider socio-technical system
  - Processing (pre-, post-)
  - Logistics
  - Applications
  - Recycling/Reuse
- What technological improvements do you suggest?

ASSESS

BUSINESS CASE

- To build a IS cluster for electrification, there should be a business case for each of the individual companies.
- What are the current barriers for investing and how can they be overcome?

ASSESS

DATA

- To collaborate data has to be shared among partners
- What improvements to achieve collaboration with data do you suggest?

ASSESS

INFRASTRUCTURE

- Clusterization affects the need for infrastructure connections. Hence, the infrastructure should be upgraded and new linkages should be established.
- What challenges regarding infrastructure do you see and how can they be overcome?

ASSESS

GOVERNANCE

- To facilitate the transition towards an industrial symbiosis cluster for electrification changes in the governance structure may be required.
- What changes do you envision?
- What should be the role of local authorities?
- What can we learn from the governance structure of other clusters (e.g. Chemelot where an internal service company plays a key role in the transition)?

ASSESS

POLICY

- To enable the transition towards an industrial symbiosis cluster for electrification adequate (and cluster-specific) fiscal and financial incentives and regulatory instruments should be put in place at all governance levels.
- What fiscal and financial incentives and regulatory instruments are required?

Figure 3.6 - Evaluation criteria used in the stakeholder workshop.

4. TECHNO-ECONOMIC ANALYSIS OF INTEGRATED TECHNOLOGY CONCEPTS

One of the subparts of this study is a techno-economic analysis of two different integrated technology concepts. The steps taken in this part have been discussed in Chapter 3.

In the following sections, the opportunities explored in this study through desk research and exploratory interviews with companies in the Botlek are outlined (Section 4.1). Section 4.2 discusses the design of the integrated technology concepts (ITC's). An initial design of these ITC's was made based on the exploratory interviews. Subsequently, in-depth interviews were held to work out the ITC's in further detail.

4.1 EXPLORATION OF OPPORTUNITIES

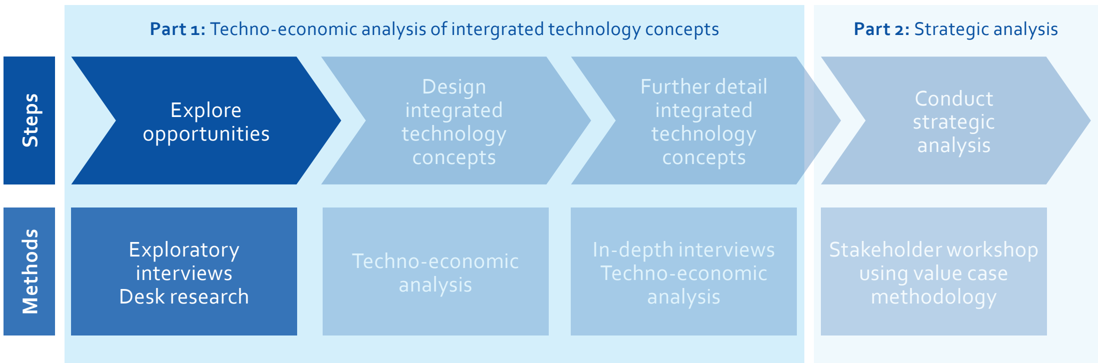

Figure 4.1 - Position of the "Explore opportunities" step in the research approach.

As a first step in this study, opportunities for symbiosis-based electrification were explored (see Figure 4.1). This was done through desk research and exploratory interviews with various companies in the Botlek cluster.

Through desk research, energy and material streams were mapped and quantified, allowing to calculate the consumption of steam, natural gas and residual gas and CO_2 emissions for different industrial processes. Moreover, several decarbonization options were identified. These data formed the starting point for the design of integrated technology concepts (ITC's).

The options for different ITC's were discussed with the companies in the Botlek cluster through exploratory interviews. Based on companies feedback, two integrated technology concepts (ITC's) were selected, which were then further detailed (see Section 4.2).

4.1.1 MAPPING OF ENERGY AND MATERIAL STREAMS AND EMISSIONS IN THE BOTLEK CLUSTER

Ample research has been done already on feedstock and product volumes, energy and material streams, CO_2 emissions, etc. Figure 4.2 contains an overview of the different databases consulted for the desk research within this study and the information obtained from each database.[2]

MIDDEN DATABASE AND REPORTS

- Information on mass and energy balances Feedstock/products
- CO_2 emissions from NEa
- Process description + residual streams (from reports. partially accurate)
- Overview of decarbonization options

PBL DATABASE FOR BOTLEK

- Info on existing exchange of steam and fuel gas
- CO_2 emissions data (NEa)
- Products. feedstocks flows
- Energy flows for each company (steam. electricity, natural gas demand)

Figure 4.2 - Overview of the databases consulted for this study and the information obtained from each database.

Through consultation of these databases several decarbonization options were identified:

- **Short term (2030)**
  - Waste heat upgrade via heat pumps
  - Low pressure steam upgrade via mechanical vapour recompression (MVR)
  - Small scale electrical boilers (<100 MWe)
  - Blue hydrogen production via fuel gas (H-vision concept)
  - Electric compressor turbines
- **Medium term (2040)**
  - Electric furnaces
  - Large scale electrical boilers (>100MWe)
  - Green hydrogen production
  - CCU: production of methanol using CO_2
  - Methanation (production of SNG via reaction with CO_2)
- **Long term (2050)**
  - Methane pyrolysis via plasma (H2 and ethylene production)
  - CCU: formic acid production via electrochemical conversion of CO_2

Using the databases mentioned, energy and materials streams were mapped and the potential gains of electrification in the Botlek were calculated. The current energy and material flows are visualized in Figure 4.3.

2 Citations: (De Haas & Van Dril, 2022), (PBL Netherlands Environmental Assesment Agency) (Deltalinqs)

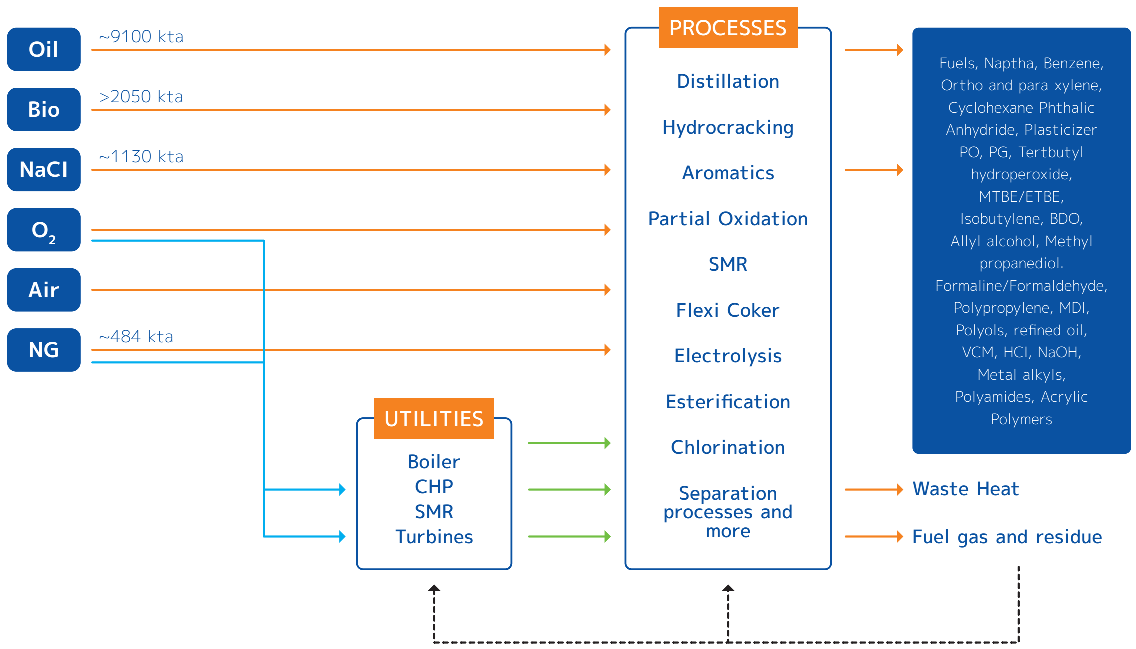

Figure 4.3 - Visualization of current energy and material flows in the Botlek area. The orange arrows represent feedstocks, which feed the chemical production processes, while the blue arrows represent fuels for utilities. Waste heat and fuel gas and residues are fed back to provide energy for utilities and production processes (dotted black arrows).

As becomes apparent from Figure 4.3, the Botlek cluster, which is dominated by chemical plants, relies heavily on fossil fuels, both as feedstock and as fuel for steam and heat production (utilities).

Table 4.1 shows some key consumption and emission indicators of the Botlek area. From Table 4.1 it can be concluded that the consumption of residual gas is significant and even larger than the consumption of natural gas. Currently, all steam is generated by burning natural gas or residual gas.

Table 4.1 - Key consumption and emission indicators of the Botlek area (baseline year: 2019).

Key indicator	Value
Scope 1 CO_2 emissions	~6.5 megaton per year
Natural gas consumption	~1100 MW
Residual gas consumption	~1600 MW
Steam consumption	~1900 MW

4.1.2 RESULTS FROM THE INTERVIEWS

Before holding exploratory interviews, first all industrial companies located in the Botlek area were listed (Figure 4.5).

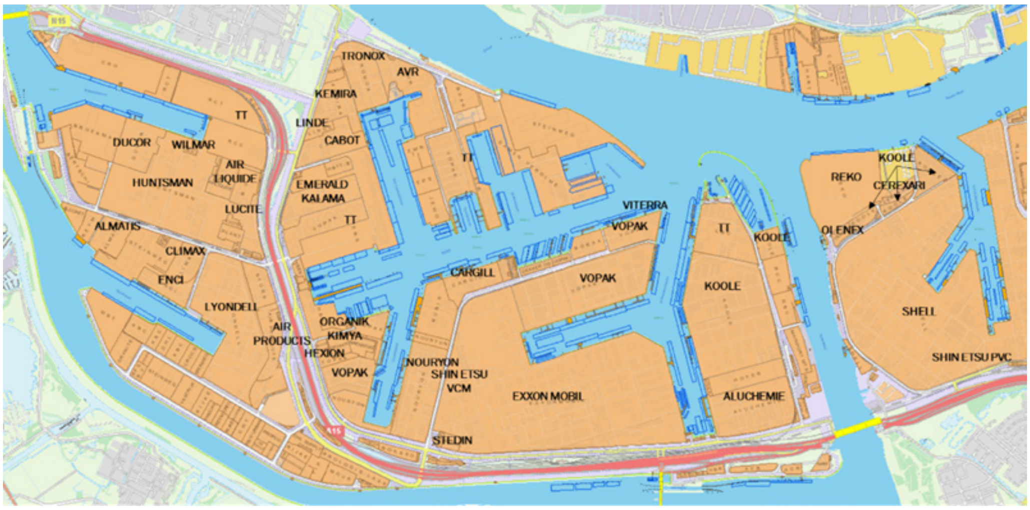

Figure 4.4 - Companies in the Botlek area

From the interviews, it was concluded that most companies do have residual flows, which they now either incinerate themselves for steam production or exchange with neighbors, who incinerate these flows, also for energy provision, and in some cases return steam.In general, these residual flows are highly diluted/polluted, whereas the volumes per individual site are relatively limited.

Furthermore, the Botlek cluster is already highly integrated (comparable to e.g., German "Verbund" site). Industrial symbiosis is already existent in the cluster to some extent,

During the interviews, the companies indicated that they were interested in two of the suggested integrated technology concepts:

1. **Integrated technology concept 1:** electrification + blue methanol production. In this integrated technology concept, electrification of steam and heat production is implemented and residual streams are repurposed to produce blue methanol.

2. **Integrated technology concept 2:** electrification + blue hydrogen production. In this integrated technology concept, electrification of steam and low temperature heat production is implemented and residual streams are repurposed to produce blue hydrogen.

Using techno-economic analyses, these two ITC's were worked out in further detail, with the end goal of starting pilot projects in the Botlek area. For the design and technical specifications of these ITC's, see Section 4.2.

4.2 DESIGN OF INTEGRATED TECHNOLOGY CONCEPTS

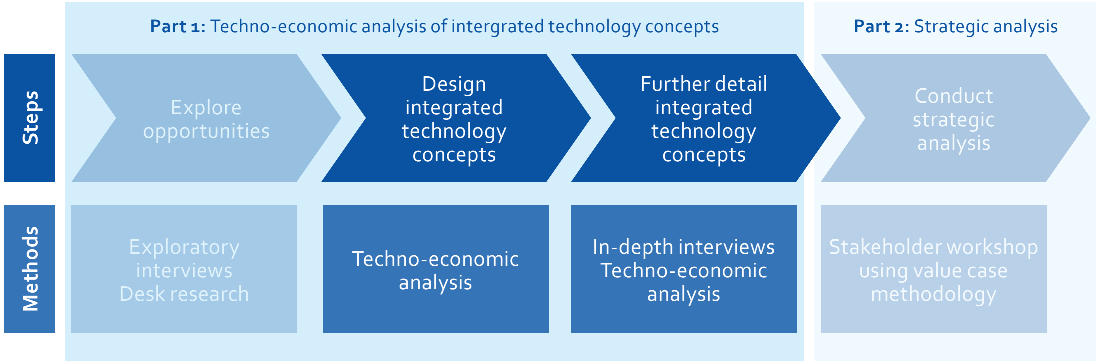

Figure 4.5 - Position of the "Design of integrated technology concepts" and "Further detail integrated technology concepts" steps in the research approach.

Upon selection of the two integrated technology concepts (ITCs), these concepts were designed. This step in the study is schematically shown in Figure 4.5. After an initial design was made, this design was discussed with the companies in a second round of in-depth interviews. Using the companies feedback, the ITCs were further detailed, resulting in the final designs outlined in this section. Note that the ITCs were designed based on publicly available data (see Section 4.1.1) that concerns all companies in the Botlek cluster, not just the companies interviewed.

In Section 4.2.1, the design approach for the ITCs is outlined. Then, the respective ITC's are discussed in Sections 4.2.2 and 4.2.3

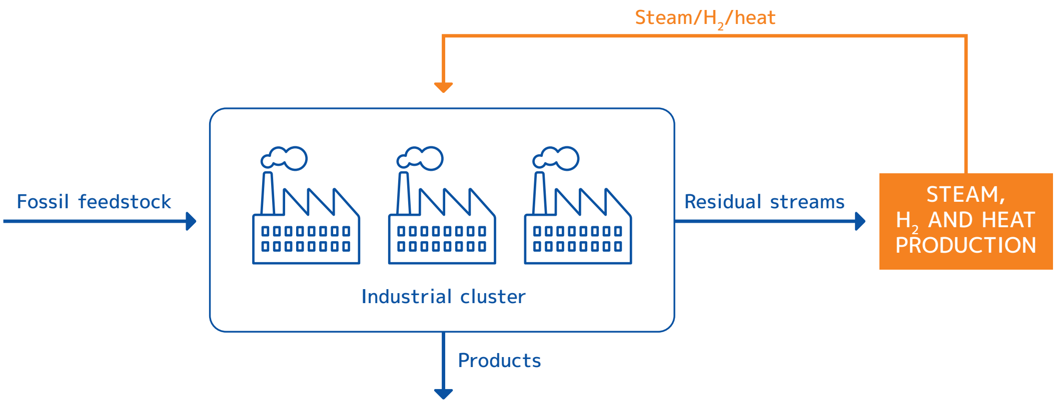

Figure 4.6 - Current situation in many industrial clusters: residual streams (gases or liquids), by-products from the production process, is used to generate steam, hydrogen and heat.

4.2.1 DESIGN APPROACH

The starting point of the integrated technology concepts is to not only address electrification, but to also focus on industrial symbiosis by taking into account the repurposing of residual streams that companies may have. In the current situation in many production plants, including those in the Botlek area, industrial processes produce residual streams (gas or liquids), which are used in turn for the generation of steam, hydrogen and heat (see Figure 4.6).

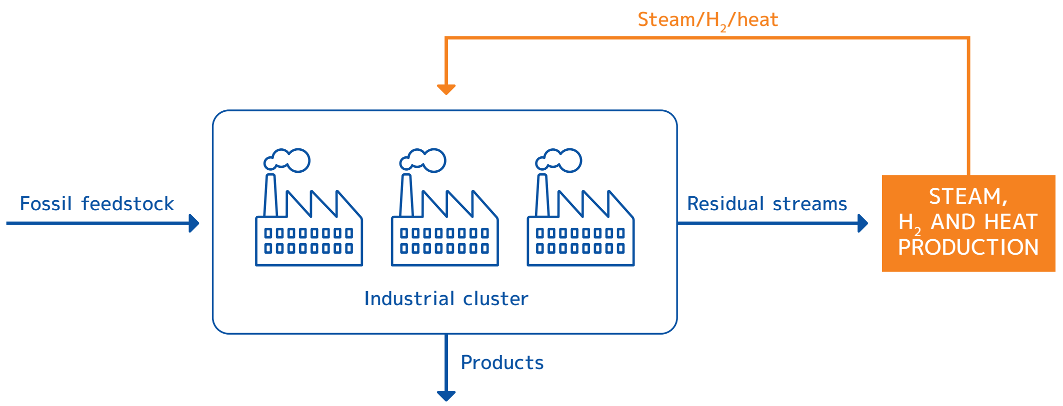

Figure 4.6 - Current situation in many industrial clusters: residual streams (gases or liquids), by-products from the production process, is used to generate steam, hydrogen and heat.

However, electrification will make residual streams redundant as the generation of steam (electric boilers), hydrogen (electrolysers) and heat (heat pumps) will rely on electricity instead. If steam-driven compressors are also electrified, steam demand can be reduced and the overall boiler capacity can be decreased. Note that with the current state of technology, only the production of low-temperature heat and steam (<200°C) can be electrified in the short term. Hence, the residual streams resulting from production processes will need to be repurposed. The designed integrated technology concepts take the repurposing of residual streams as a starting point, see Figure 4.7.

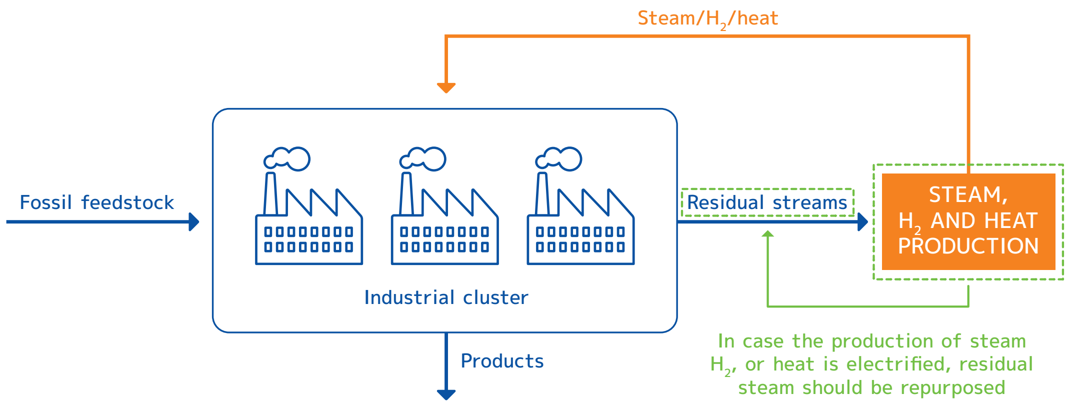

Figure 4.7 - Basis for designing the integrated technology concepts: repurposing of residual gas.

The integrated technology concepts are built up based on three different electrification routes and three different residual streams repurposing routes, see Figure 4.8.

Regarding electrification, three routes were explored:

1. Electrification of steam production using electric boilers
2. Electrification of hydrogen production using electrolysers
3. Electrification of low temperature heat (<200°C) using heat pumps.

Regarding the repurposing of residual streams, also three routes are possible, depending on the composition of the residual streams (e.g. methane-rich or nitrogen-rich):

1. Repurposing residual streams for blue hydrogen production
2. Repurposing residual streams for syngas production
3. Repurposing residual streams for methanol production

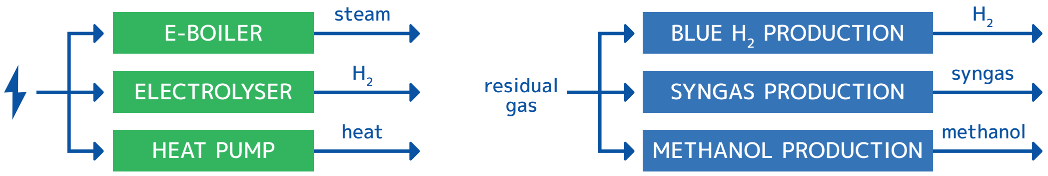

Figure 4.8 - Routes for electrification and residual streams repurposing considered in the integrated technology concepts.

Note that the mentioned electrification routes could, in principle, be considered as stand-alone solutions, without considering routes for residual streams repurposing. This approach has been the focus of electrification studies up until now (see Section 2). However, the approach in this study combines both types of routes.. This combination of routes for electrification and residual streams repurposing has been the starting point of the integrated technology concept design.

Eventually two integrated technology concepts were designed based on the routes visualized in Figure 4.8:

1. Integrated technology concept 1: electrification + blue methanol production (see Figure 4.9). In this integrated technology concept, electrification of steam and low heat production is implemented and residual streams are repurposed to produce blue methanol.
2. Integrated technology concept 2: electrification + blue hydrogen production (see Figure 4.10). In this integrated technology concept, electrification of steam and low temperature heat production is implemented and residual streams are repurposed to produce blue hydrogen.

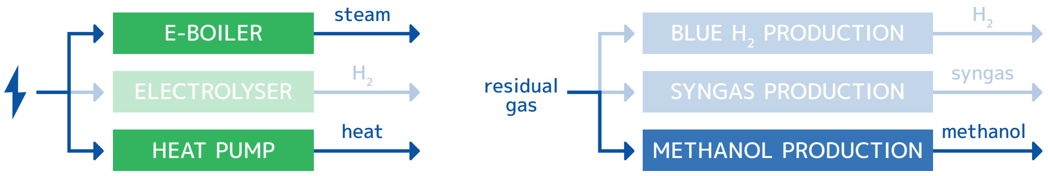

Figure 4.9 - Visualization of the principle of integrated technology concept 1.

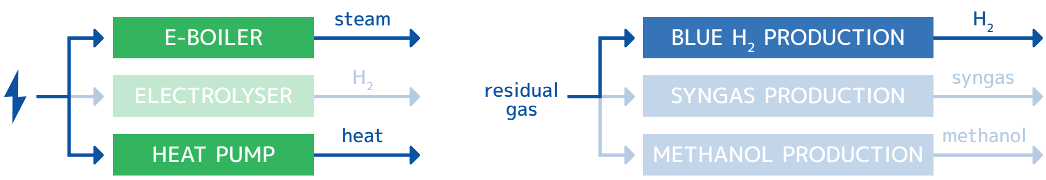

Figure 4.10 - Visualization of the principle of integrated technology concept 2.

By implementing the two suggested integrated technology concepts all steam production in the cluster could be electrified, leading to a decrease in scope 1 CO_2 emissions against a net abatement cost specified in Table 4.2.

Table 4.2 - Potential gains (avoided CO_2 emissions, on-site steam production that could be electrified and economic gains) of the two integrated technology concepts considered.

Potential gain	Quantity
Scope 1 CO_2 emissions avoided	3.9 Mton/year
On-site steam production that could be electrified	61 PJ/year
Net CO_2 abatement cost	30-67 euro/tonne CO_2 (depending on the ITC)

In the following section, these two integrated technology concepts are explained in detail.

4.2.2 INTEGRATED TECHNOLOGY CONCEPT 1: ELECTRIFICATION + BLUE METHANOL PRODUCTION

The integrated technology concept visualized in Figure 4.11, targets steam and low temperature heat production systems. Heat pumps (for heat demand below 200°C) and electric boilers are responsible to meet the targeted energy demand. The residual methane-rich fuel gas is used to produce methanol (methane reforming followed by synthesis gas conversion to methanol). The CO_2 produced during the methane reforming is transported and stored using CCS.

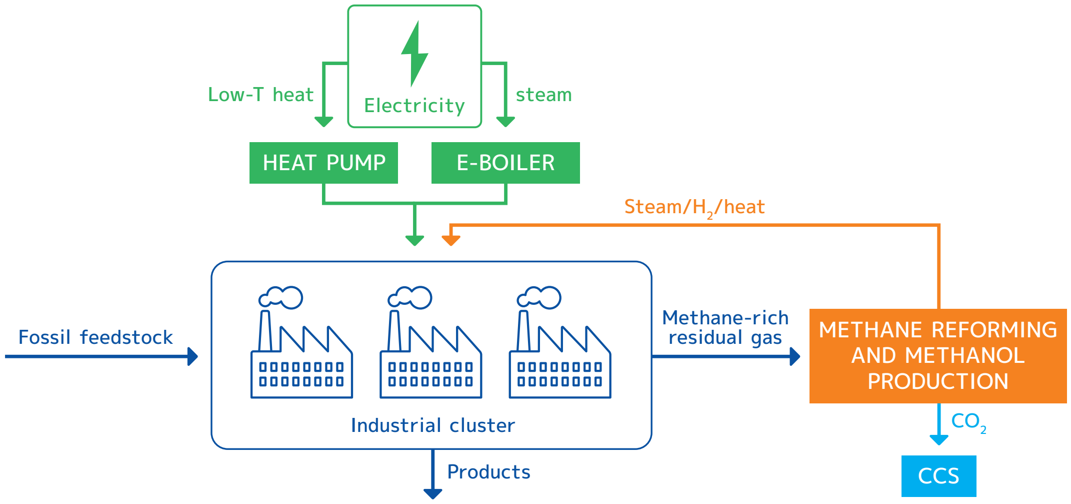

Figure 4.11 - Configuration of integrated technology concept 1: electrification of steam and heat production systems is combined with the repurposing of methane-rich residual gas to produce blue methanol using methane reforming followed by syngas conversion. The CO_2 resulting from the methane reforming is stored using CCS.

In Table 4.3, the capacities of the installations displayed in Figure 4.11, are outlined. These values result from the estimated steam and low temperature heat demand from all companies present in Botlek.

Table 4.3 - Overview of the capacity of installations in the Botlek area for integrated technology concept 1 (electrification + blue methanol production).

Type of installation	Capacity
Electric boilers	1600 MW
Heat pumps	750 MW
Blue methanol production	2300 ktonne/year ~ 1450-1680 MW
CCS	1400 ktonne/year

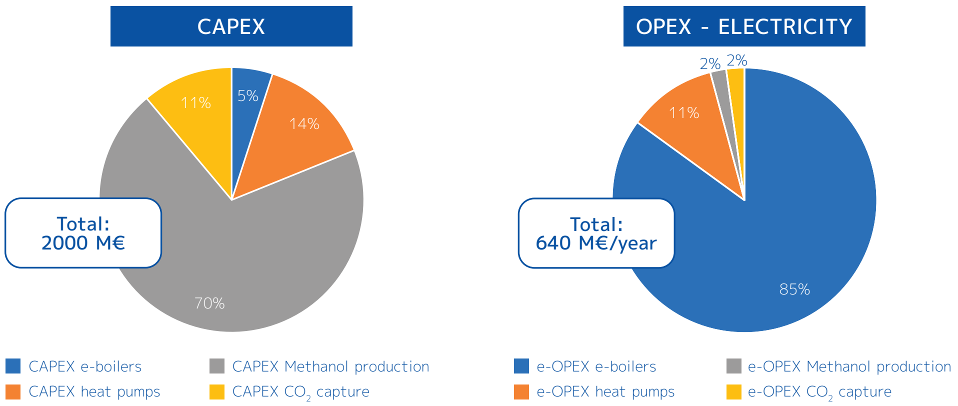

Figure 4.12 - Capital expenditures (CAPEX) and operational expenditures (OPEX) for integrated technology concept 1 (electrification + blue methanol production). Note that the OPEX only concerns electricity costs.

In Figure 4.12, the capital expenditures (CAPEX) and operational expenditures (OPEX) for integrated technology concept 1 are displayed. In turns out that with a share of 70% in the total CAPEX, the installation of a methanol production facility is the most capital-intensive part. However, on the OPEX-side, the electricity consumption of the electric boilers weighs the heaviest on the operational expenditures.

In terms of CO_2 avoidance costs, integrated technology concept 1 yields the following cost breakdown, yielding a net CO_2 abatement cost of 30 €/ton (see Figure 4.13). Though the OPEX for electricity is quite high, it is compensated for by a large revenue for the methanol produced. That being said, the methanol price is an important driver for this revenue and is among the key assumptions behind these calculations, which can be found in Table 4.4.

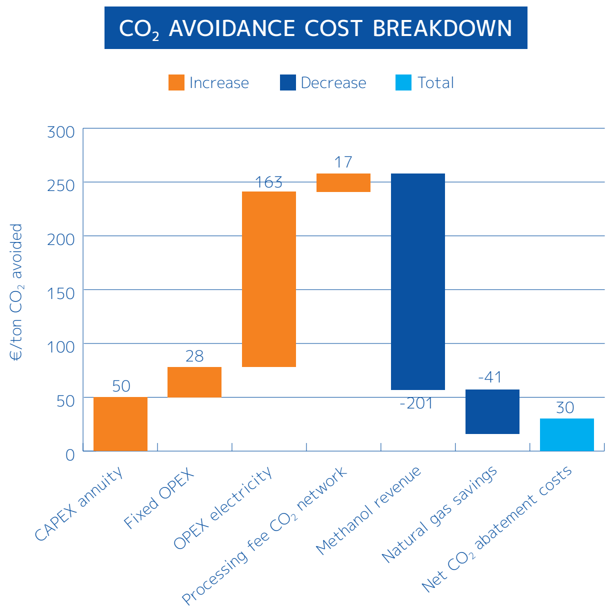

Figure 4.13 - CO_2 abatement cost breakdown for integrated technology concept 1 (electrification + blue methanol).

Table 4.4 - Key assumptions in the calculations of CAPEX, OPEX and CO_2 avoidance costs, integrated technology concept 1.

Factor of interest	Value
Electricity price	50 euro/MWh
Natural gas price	20 euro/MWh
Methanol price	320 euro/tonne ~ 50-58 euro/MWh

4.2.3 INTEGRATED TECHNOLOGY CONCEPT 2: ELECTRIFICATION + BLUE HYDROGEN PRODUCTION

The second integrated technology concept (visualized in Figure 4.14), like the first one, also targets steam and low temperature heat production systems. Conventional boilers are substituted by heat pumps (for heat demand below 200°C) and electric boilers. Here, fuel gas is used to produce blue hydrogen via autothermal reforming (ATR). The CO_2 produced during ATR is transported and stored (CCS).

Blue hydrogen could, in theory, be used either as fuel for furnaces/boiler or as feedstock. However, during the interviews, most if the companies indicated that using hydrogen as fuel would be unfavorable as it has more value as feedstock.

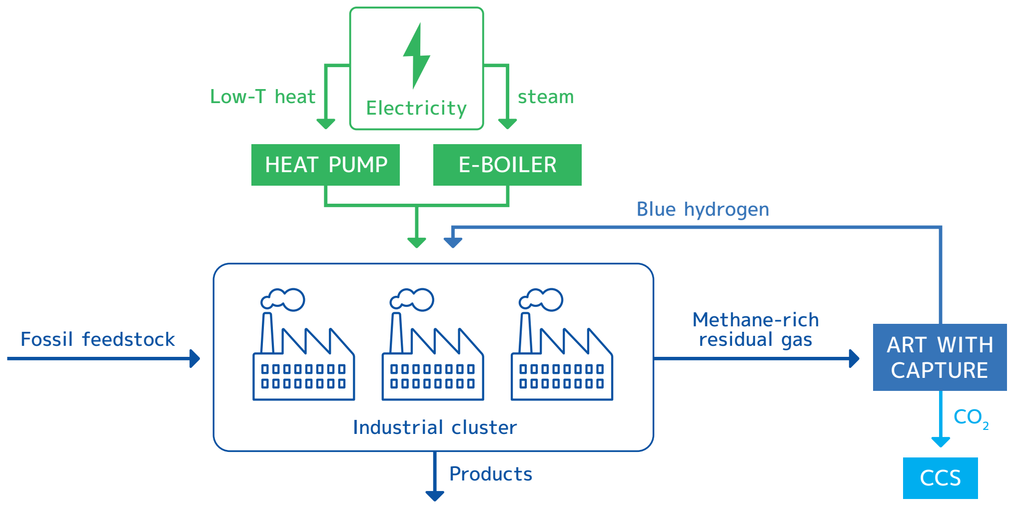

Figure 4.14 - Configuration of integrated technology concept 2: electrification of steam and heat production systems is combined with the repurposing of methane-rich residual gas to produce blue hydrogen using autothermal reforming (ATR). The CO_2 resulting from ATR is stored using CCS.

In Table 4.5, the capacities of the installations displayed in Figure 4.14, are outlined.

Table 4.5 - Overview of the capacity of installations in the Botlek area for integrated technology concept 2 (electrification + blue hydrogen production).

Type of installation	Capacity
Electric boilers	1300 MW
Heat pumps	750 MW
Blue hydrogen production	300 ktonne/year
CCS	2500 ktonne/year

The CO_2 avoidance cost breakdown for integrated technology concept 2 is shown in Figure 4.15. Comparing the integrated technology concepts, we can see that the net CO_2 abatement costs are substantially larger for integrated technology concept 2: 67 euro/tonne CO_2 avoided compared to 30 euro/tonne CO_2 avoided for integrated technology concept 1. The main reason for this is the expected revenue from blue hydrogen production, which is lower than for blue methanol.

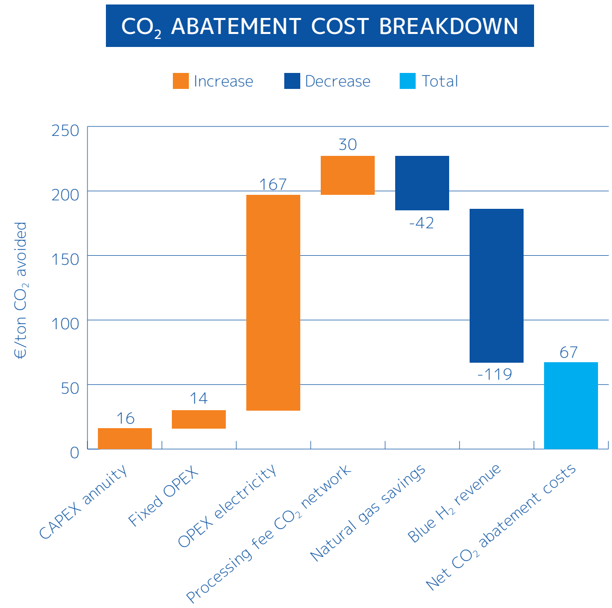

Figure 4.15 - CO_2 abatement cost breakdown for integrated technology concept 2 (electrification + blue hydrogen production).

In Figure 4.16, the CAPEX and OPEX calculations and breakdown are shown for the configuration of integrated technology concept 2 are shown. Overall, the CAPEX is lower than for integrated technology concept 1 (2000 million euros), while the OPEX is comparable. It turns out that the share of residual gas repurposing in the total CAPEX is lower for integrated technology concept 2 than for integrated technology concept 1. On the other hand, the revenue from blue hydrogen production is also lower, resulting in an overall higher net CO_2 abatement cost (see Figure 4.15). This revenue value assumes a blue hydrogen price of 1500 euro/tonne, see Table 4.6. Again, assumptions on materials prices are quite relevant for the analysis.

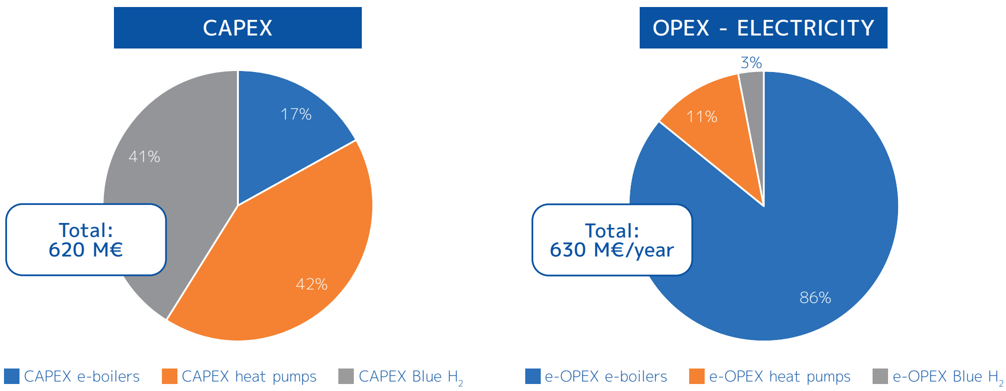

Figure 4.16 - Capital expenditures (CAPEX) and operational expenditures (OPEX) for integrated technology concept 2 (electrification + blue hydrogen production). Note that the OPEX only concerns electricity costs.

Table 4.6 - Key assumptions in the calculations of CAPEX, OPEX and CO_2 avoidance costs, integrated technology concept 2.

Factor of interest	Value
Electricity price	50 euro/MWh
Natural gas price	20 euro/MWh
Blue hydrogen price	1500 euro/ton

5. STRATEGIC ANALYSIS

As industrial symbiosis is a collaborative approach it relies on co-operation between various actors. From an operational perspective, this implies that new relationships are formed, sometimes between previously unrelated companies. Moreover, the traded-by-products are typically outside the core business of the supplier. This all therefore requires some degree of shared strategic visions and collective decision-making, demanding mutual recognition, trust, and information sharing, and often some sort of central organization (Lowe, 1997; L.W. Baas, 2004; Chertow, 2007).

The second part of this study focussed on addressing these topics in the Botlek cluster. This step of the study in the research approach is highlighted in Figure 5.1.

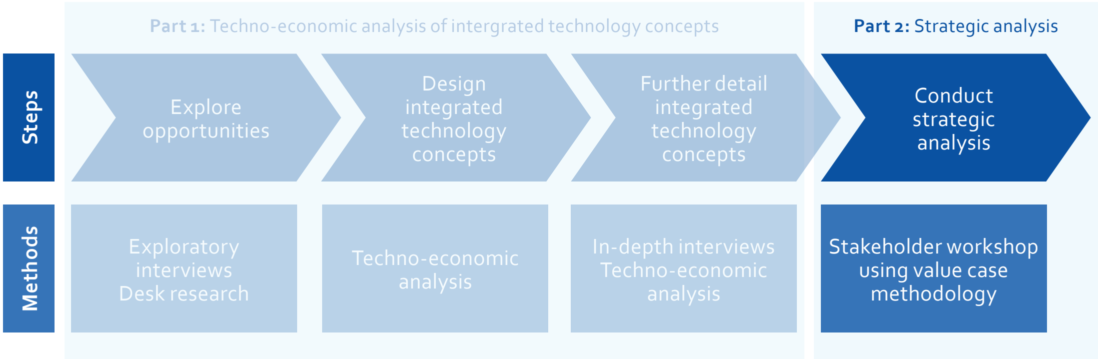

Figure 5.1 - Position of the "Conduct strategic analysis" step in the research approach.

5.1 DESIGN OF THE STAKEHOLDER WORKSHOP

To collect visions among actors in the Botlek cluster a stakeholder workshop was planned, based on the value case methodology of the strategic business analysis department of TNO. With the Value Case Methodology (VCM) stakeholder values can be mapped in a comprehensive, independent and objective manner. This mapping can then be used for aligning their objectives. As such, VCM allows for broad support for an investment decision in a joint project and achieving collective action. The VCM consists of four steps: design, quantification, valuation and alignment (for more information see below).

THE VALUE CASE METHODOLOGY (DITTRICH & VAN DIJK, 2013)

"The goal of the VCM is first to create a form of mutual understanding between the stakeholders so that they are aware of values of other stakeholders and of the extent to which each particular value should be addressed according to each stakeholder. In short capturing the motivation and wishes of the individual stakeholders in a more common language.

Next, the VCM will challenge stakeholders to look at the proposed project afresh, from their mutual understanding. This may stimulate the stakeholders to reshape or redefine the goal or desired outcomes in order to fulfil the wishes of all stakeholders. Once a level of consensus has been reached on which values and level of innovation the project should address, stakeholders will be prepared to invest and the joint project can commence.

The VCM is aimed at positive decisions to give the go-ahead for the innovation project. Once the goals and the innovation project itself are defined, stakeholders are selected and an initial overview of who-does-what is produced."

5.2 RESULTS OF STAKEHOLDER WORKSHOP

5.2.1 GENERAL BARRIERS

Industrial symbiosis has been recognized as an effective approach for environmental improvements at the regional level. Numerous technical solutions have been discovered for energy, water, by-product and waste reuse between neighboring industries. Nevertheless the presence of feasible technical solutions does not guarantee the uptake of new synergies due to limitations coming from nontechnical barriers, such as concerns over competitiveness that hinder collaboration between commercial companies or absence of enabling policies.

Previous studies have inventoried the IS issues and enablers that can be found at the regional level. Golev, Corder & Giurco (2015) have grouped most of the approaches in seven categories, these range from the commitment to sustainable development to economic barriers (Table 7.1).

Table 7.5.1 Barriers and enablers to industrial symbiosis (Golev, Corder, & Giurco, 2015)

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

5.2.2 BARRIERS IDENTIFIED IN THE CASE OF THE BOTLEK

During the interviews and the stakeholder workshop, several barriers to symbiosis-based electrification in the Botlek area were identified. These have been categorized in Table 7 based on the framework proposed by Golev, Corder & Giurco (2015).

Table 7.5.2 - Barriers to symbiosis-based electrification identified among companies in the Botlek area.

Category	Barriers identified
1. Commitment to Sustainable Development	Many companies in the Botlek cluster have committed to the Rotterdam Climate Agreement, which aims for a 50% CO_2 reduction in 2030 compared to 1990 levels. Sustainability is on the agenda of all companies, though most companies are in the orientation phase with regard to sustainability measures. Many companies appear to be taking a "wait-and-see" stance as new infrastructure or infrastructure upgrades (for electricity, hydrogen and CO_2) are a precondition for implementing sustainability measures and the costs of low-carbon commodities remain too high for a sustainable industry to be viable. Within the Botlek area, a number of working groups have been active for some time on the implementation of collective solutions, such as the chlorine cluster and steam pipe. However, progress appears to be challenging. The companies do recognize the need for a collective solution when it comes to the repurposing of residual streams.
2. Information	There is insufficient public available qualitative and quantitative data on waste streams and local industries' material, water and energy requirements in the Botlek area. Making this information available requires a format that secures collection and storage of data, which poses a considerable challenge. In addition, waste streams have to be defined more precisely in terms of composition and volumes.
3. Cooperation	With regards to cooperation there is hesitation of sharing of company-specific information due to commercial sensitivities. Only if sufficient companies commit to cluster cooperation the willingness to share information would be present. In addition, companies mentioned that they wanted to keep the management of residual flows within their own boundaries.
4. Technical	Several technical barriers are present: Residual streams vary in quality The new system requires upgrades in the grid capacity. The lead times for these upgrades are considerable (up to 10 years). The variability in the renewable energy supply has to be taken into account as some industrial processes require a baseload supply of energy. There is a common concern among the companies regarding the availability of renewable electricity to enable large-scale electrification.

Category	Barriers identified
5. Regulatory	The following regulatory issues emerged during our study: 1. As the national government is changing legislation and requirements on a frequent basis, it results in unclear boundary conditions. Therefore, companies have refrained from formulating long-term decarbonization roadmaps. 2. While the Dutch government's SDE++ subsidy aims to promote the adoption of sustainable technologies in industry, the SDE++ is an exploitation subsidy: it reimburses the difference between the costs of reducing CO_2 emissions and the returns. Therefore, it does not take away the investment threshold. As a result, the incentive provided by the SDE++ is often not strong enough to trigger investments in electrification. Also, some technologies, such as electric compressor turbines, are not yet covered in the SDE++. Moreover, SDE++ currently only subsidizes electric boilers for 3000 full load hours per year. Hence, it will be challenging to arrive at a positive business case for 8300 full load hours (Marsidi, Dam, & Lensink, 2021). 3. Furthermore, there is uncertainty among companies as to how the CO_2 impact of implementing symbiosis-based electrification will be assessed. 4. The 2021 amendment to the EU Renewable Energy Directive (European Commission, 2021) dictates that CCU for the purpose of the production of renewable fuels of non-biological origin (RFNBOs) can only be counted towards emission saving targets if 70% of greenhouse gas emissions are reduced (European Commission, 2023).
6. Community	There seems to be little community awareness in the Botlek area which explains the limited strategic mindset to reach carbon neutrality as a cluster. Moreover, the interests of the different companies involved varies significantly and the benefits of industrial symbiosis will not be evenly distributed.
7. Economic	According to the stakeholders, there is no viable business case for large-scale symbiosis-based electrification yet. Several reasons were mentioned for this. 1. The required investments are too high. 2. The added value of repurposing residual streams is considered marginal compared to combustion. This is due to the fact that there is still uncertainty regarding the commercialization opportunities of residual flows. 3. With regard to integrated technology concept 1: the market size for blue methanol is unclear. 4. In case of a collective electric boiler facility, the steam produced will be more expensive than local production as new pipelines need to be constructed to distribute the steam from the e-boiler to all parts of the cluster. However, increasing CO_2 prices and/or gas prices may result in a positive business case. 5. Upgrading the electricity grid connection, which is needed for electrification, comes with considerable costs.

5.2.3 POTENTIAL SOLUTIONS

In the stakeholder workshop, several solutions emerged to the barriers identified, which are outlined in Table 7.

Table 7.5.3 - Potential solutions to the barriers identified as proposed in the stakeholder workshop.

Category	Potential solutions to the barriers identified
1. Commitment to Sustainable Development	Defining a common goal in the Botlek area was emphasized as the first step towards a strategic collaboration with regard to sustainable development. This goal should be the basis for a cluster-level transition path that connects companies to engage in a collaborative solution. This transition path should sketch an image of how the plants in the Botlek will be operated in the future and should give a clear answer to key questions, such as whether natural gas still play a role on the longer term (2040 and beyond) and how roles and responsibilities will be divided among the cluster.
2. Information	Transparency of the companies in the Botlek among each other was emphasized by the companies as necessary for tackling information uncertainties. However, the companies also expressed hesitancy to share data due to confidentiality. A protected environment for sharing data was proposed as a potential solution to this dilemma. This reinforces the need for a Data Safehouse, which is an ongoing project by Deltalinqs. The purpose of the Data Safehouse is to act as a secure platform for grid and infrastructure operators to review company-sensitive data about energy and material streams without exposing this data (Deltalinqs, 2021). During the stakeholder workshop, the representatives from the companies indicated that this Data Safehouse should be managed by an independent party. The companies also expressed a need for better specification of the benefits of symbiosis-based electrification. This will require more in-depth research and more detailed specification of the integrated technology concepts.
3. Cooperation	Breaking the barriers to information sharing and cooperation are closely intertwined. As mentioned above, a protected environment for sharing data will contribute to overcoming the challenge of dealing with company-specific information. Another suggestion that was made is the appointment of a third party that would be in the lead of executing projects, such as the Port of Rotterdam, Deltalinqs, a new common utility supplier (analogous to the Chemelot cluster) or DCMR Milieudienst Rijnmond (the environmental agency of the Rijnmond area) that could enforce the sustainable transition through permits (as an addendum to environmental regulations).

Category	Potential solutions to the barriers identified
4. Technical	With regard to upgrading the grid capacity, it was emphasized to involve the grid operator (Stedin) early on to make sure electricity grid is upgraded timely to enable the roll-out of concrete pilot projects, based on the integrated technology concepts, and to facilitate further electrification. Hence, communication about the capacity and timing of the electricity demand to Stedin is essential. To account for renewable electricity variability, flexibility mechanisms and buffers should be available for the cluster. No solutions were proposed for overcoming the other technical barriers introduced, i.e. the varying quality of residual streams, the maintenance of the system and the concerns regarding the sufficient availability of renewable electricity.
5. Regulatory	The Municipality of Rotterdam indicated that granting subsidies to symbiosis-based electrification projects independently from the SDE++ would be an option. This would resolve the challenges faced by the companies regarding the SDE++. Certification is required to assess the CO_2 impact of symbiosis-based electrification.
6. Community	To create more community awareness, a common goal and strategy need to be defined as mentioned under (1) Commitment to sustainable development. There was consensus among the companies that the cluster collectively should break old habits and for seek new patterns of collaboration.
7. Economic	The companies expressed the need for further detailing the business case for a sustainable industry in the Botlek cluster. Though this would not necessarily result in a viable business case, it would at least take away the current uncertainties surrounding the business case. In order to make that possible, cooperation in data gathering is needed to execute a detailed business case.

5.3 SETTING UP A DURABLE GOVERNANCE

Several barriers mentioned in the workshop can be overcome by increased mutual cooperation. In the following part we discuss the potential of durable governance to contribute to this cooperation.

While the creation of industrial clusters may improve resource efficiency and enable faster decarbonization, it may also lead to carbon lock-in due to the tendency of industrial clusters to favor incremental changes, companies having a short-term focus and companies taking independent actions (Janipour, De Gooyert, Huijbregts, & De Coninck, 2022). Hence, it is essential that a durable governance is set up in the transition process of clusters towards a carbon neutral and circular industry (Van der Reijden et al., 2021).

Van der Reijden et al. (2021) indicate that all levels of governance in transition process– 1) port/cluster authorities, 2) national governments, 3) bi-/multilateral collaboration between countries with industrial clusters and 4) the EU –have a responsibility. While the EU's and national government's main roles are to provide adequate subsidy schemes and regulatory frameworks, at the cluster level, the port or cluster authority has an important role in aligning local stakeholders and facilitating policies aimed at providing logistical and practical support (Van der Reijden, De Coninck, Khandekar, & Wyns, 2021). In the Botlek area, the Port of Rotterdam Authority takes on this role.

According to Janipour, De Gooyert, Huijbregst & De Coninck (2022) the Botlek has a good starting position as the Port of Rotterdam Authority is the landowner of the cluster and already coordinates the climate neutrality plans in the port. This may benefit the organization of the collaboration between companies towards decarbonization and circularity. However, lessons may also be drawn from other clusters, notably the Chemelot cluster, where there is a separate service company (Sitech Services BV) that manages the transition towards climate neutrality and also manages the entries for the EU ETS (Van der Reijden, De Coninck, Khandekar, & Wyns, 2021). Moreover, Chemelot has a common utility supplier (Utility Support Group BV) which handles the purchase, production, distribution and sale of utilities such as electricity, industrial gases, air and water (Chemelot, n.d.).

During the stakeholder workshop, it was suggested to appoint a third party that will be in the lead of executing projects. A new common utility supplier similar to the Chemelot cluster could be established to take on this role. An existing party could be appointed, such as FLIE, the Port of Rotterdam Authority, Deltalinqs, or DCMR Milieudienst Rijnmond (the environmental agency of the Rijnmond area) that could enforce the sustainable transition through permits (as an addendum to environmental regulations).

To design an effective governance, this study suggests to consider the appointment of a third party to resolve the resistance to collective action; being a key factor to implement large-scale symbiosis-based electrification in the Botlek area. However, the current role of the Port of Rotterdam Authority as facilitator of the transition towards climate neutrality in the cluster should be taken into account.

6. CONCLUSION & PROPOSED ACTIONS FOR FUTURE COLLABORATION

To contribute to the goal of reducing CO_2 emissions by 49% in 2030 with respect to 1990 levels in the Port of Rotterdam, as specified in the Rotterdam Climate Agreement (Energieswitch - Rotterdamse Klimaat Alliantie, 2019), the opportunities for symbiosis-based electrification in the Botlek area were explored. In this approach, the short-term reduction of CO_2 emissions through electrification from an industrial symbiosis perspective was considered. As such, an important issue that arises in the electrification of heat and steam production was tackled: the displacement of residual streams that are currently used to fuel heat and steam production. In the considered symbiosis-based electrification approach, these residual streams are repurposed for the production of additional valuable chemicals. The assessment focuses on the Botlek area and presents a both techno-economic analysis and strategic analysis.

In the techno-economic analysis, integrated technology concepts (ITC's) were designed focusing on electrification using e-boilers and heat pumps in combination with repurposing of residual streams for either blue hydrogen (concept 2) or blue methanol production (concept 1). Comparing the integrated technology concepts, the net CO_2 abatement costs are substantially larger for integrated technology concept 2: 67 euro/tonne CO_2 avoided compared to 30 euro/tonne CO_2 avoided for integrated technology concept 1. The main reason for this is that the expected revenue from blue hydrogen production is lower than for blue methanol.

As part of the strategic analysis, a stakeholder workshop took place in Plant One in Rotterdam in the end of May 2022 to analyze the value chain of these integrated technology concepts together with the stakeholders. This involved identifying the position of each stakeholder in the value chains and the exchanges of materials and energy flows. Moreover, barriers related to commitment, information, cooperation, technology, regulations, community and economy were identified and discussed. An important barrier to cooperation that was identified is the hesitation among companies of sharing company-specific information due to commercial sensitivities. Regarding community, it seems to exist little community awareness in the Botlek area, which explains the limited strategic mindset to reach carbon neutrality as a cluster. Moreover, the interests of the different companies in the cluster varies significantly and the benefits of industrial symbiosis would not be evenly distributed. There are also economic barriers present, such as the marginal added value of repurposing residual streams compared to combustion. This is due to the fact that there is still uncertainty regarding the commercialization opportunities of residual flows. There are just a few examples of the existing barriers to symbiosis-based electrification that were mentioned in the stakeholder workshop. Potential solutions to these barriers were mentioned during the workshop, for instance a protected environment for sharing data would contribute to overcome the hesitation of sharing company-specific information.

Phase 1 of the Electrification Blueprint Botlek study was meant originally to start up pilot projects. However, there is currently little interest from the companies' side. In this project, assistance to the innovation ecosystem of the Botlek cluster was offered by improving systemic conditions through providing financing and new knowledge. It could be that these two were not what was needed to kickstart collaborative change. Other possible activities that improve systemic conditions are networking, leadership, talent, culture, infrastructure and market demand. These may substantially lower the entry barriers for new entrepreneurial projects in the cluster, and might speed up the time to market of innovations (Stam, 2014). Further exploring the mentioned topics is a suggestion for future research.

Based on the solutions proposed during the stakeholder workshop four steps were identified as necessary for enabling large-scale symbiosis-based electrification in the Botlek, see Figure 8.6.1.

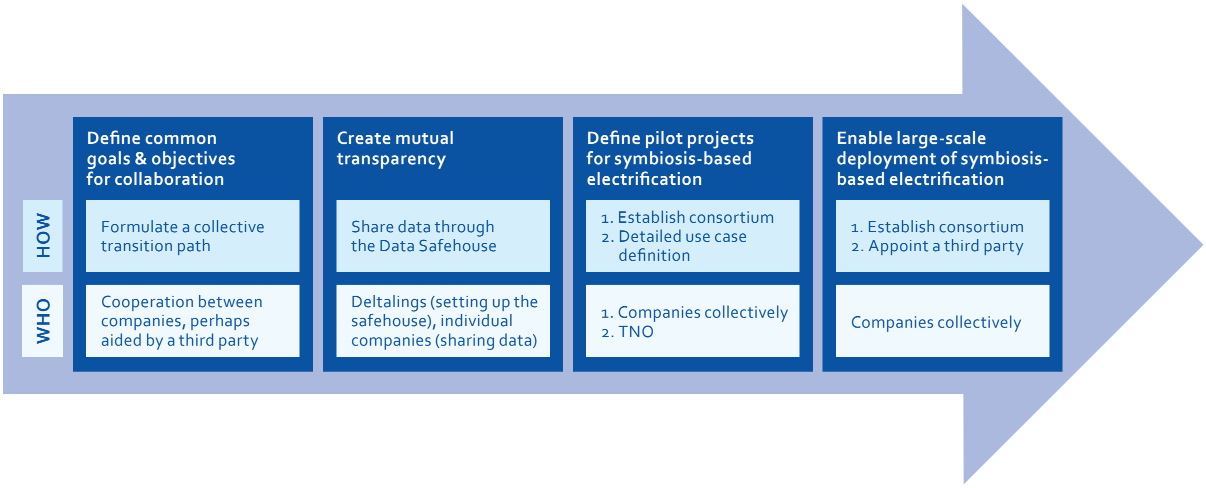

Figure 8.6.1 - Four steps towards large-scale symbiosis-based electrification in the Botlek area.
The "how" indicates how this step can be achieved; "who" indicates which party is in the lead for executing this step.

1. **Define common goals & objectives for collaboration.** As became apparent from the stakeholder workshop, it is important that companies in the Botlek area start by defining common goals and objectives for collaboration. This can be achieved by collectively formulating a transition path for the Botlek area, giving insight into common opportunities and barriers and answering key questions regarding the way the plants in the Botlek will be operated in the future, e.g. when it comes to the usage of natural gas. This ensures a shared starting point for all the companies involved and will connect companies to engage in a collaborative solution. Involving a third party to aid the companies in formulating such a transition path is a possibility. The transition path should link to existing initiatives.

2. **Create mutual transparency.** An important obstacle on the road towards large-scale deployment of symbiosis-based electrification is the currently existing hesitancy among companies to share data due to confidentiality. This problem can be resolved by a Data

Safehouse, a secure platform for grid and infrastructure operators to review company-sensitive data about energy and material streams without exposing this data (Deltalinqs, 2021). Deltalinqs and the Port of Rotterdam already working on this safehouse; the possible large-scale deployment of symbiosis-based electrification reinforces the need for such a platform.

3. **Define pilot projects for symbiosis-based electrification.** Based on the integrated technology concepts, concrete pilot projects can be defined that bring the Botlek area (and potentially other clusters in the Port of Rotterdam) a step closer to large-scale symbiosis-based electrification. However, this requires a large number of companies to commit to form a consortium to execute these pilot projects. This consortium should not only provide resources (funding, facilities and personnel) for the execution of projects but also detailed data on energy and material streams. In this concept, TNO can work out the integrated technology options in more depth, including a detailed business case analysis. Possibly, the Municipality of Rotterdam can grant subsidies to the pilot projects. Therefore, there should be close contact between the consortium and the municipality.

4. **Enable large-scale deployment of symbiosis-based electrification.** The large-scale roll-out of symbiosis-based electrification to work towards the goals and objectives set in the transition path (see step 1), requires an even broader consortium including the majority, if not all, companies in the Botlek area. A third party will be appointed that will be in charge of the project execution, e.g:
    a. FLIE
    b. The Port of Rotterdam Authority
    c. Deltalinqs
    d. A new common utility supplier (analogous to the Chemelot cluster)
    e. DCMR Milieudienst Rijnmond (the environmental agency of the Rijnmond area) that could enforce the sustainable transition through permits (as an addendum to environmental regulations).

To enable this large-scale deployment, it is important that Stedin (the grid operator) is involved timely in the process as the electricity grid needs to be upgraded accordingly, which will take several years to complete. Hence, Stedin should be involved timely about the grid connection and transport capacities required for large-scale symbiosis-based electrification.

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