Assess the future social acceptance of sustainable heating system in Amsterdam Southeast by using Cross-Impact Balances analysis

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Assess the future social acceptance of the sustainable heating system in Amsterdam Southeast by using Cross-Impact Balances analysis

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Preface

Renewable energy has attracted more and more attention in recent years. The increasing public awareness of environmental protection requires more sustainable energy solutions to reduce the carbon footprint. However, the public attitudes of some specific renewable energy solutions over the long time horizon of energy projects are often hard to forecast. This uncertainty increases the potential risk in the lack of social acceptance of the sustainable energy transition, which can result in social resistance. The basis for this project stemmed from my interest in the inhabitants' criteria dilemmas for sustainable heating system designs in Amsterdam Southeast. Although the Covid-19 situation this year has caused many difficulties in this project, for example, the less efficiency in communication via online meeting, we still got through challenges and finished the thesis.

I would like to express my sincere gratitude to the graduation committee. I wish to thank Prof. Ibo van de Poel and Dr. Emile Chappin for providing valuable feedback and advice to help me to improve the thesis continuously. They also provided me with helpful guidance beyond this graduation project itself and made me understand the approaches to deal with other similar research problems.

I would like to thank my external supervisors Tristan and Paul, who give me a significant amount of help throughout the research processes. I really appreciate their efforts to give me comments to my every update of thesis during our weekly meetings and guide me with great patience. I could have never finished this project without their help.

I would like to thank Mr. Richard Ruijtenbeek from the city of Amsterdam for his effort and time in helpfully providing me with the necessary knowledge regarding the heating energy network design and answering all my questions. I would also like to thank all the participants in the interviews and workshop. Their professional knowledge and judgements are critical inputs for the conceptualized models in this research. Through communication with these experts, I learned a lot about the technology innovation and business model in the district heating system, which also broadened my horizons to the future sustainable energy development.

Special thanks to my parents who supplied me with important material and emotional supports to finish my graduation project and master program at TU Delft.

Huayi Sun

December, 2020

Executive summary

The National Climate Agreement asks for a 49% reduction in GHG emissions in the Netherlands by 2030 and 95% reduction by 2050, compared to 1990 levels. To accomplish this goal, it is necessary to accelerate the energy transition from fossil-based to zero-carbon. The city of Amsterdam plans to phase out fossil energy source in the future district heating and cooling system in Amsterdam Southeast. However, there are numerous challenges in implementing sustainable energy projects. The lack of social acceptance of energy consumers is one of the potential risks that can slow down or even stop the sustainable energy system deployment.

It is essential to consider all the potential issues beforehand in the planning phase. Energy projects often have long time horizons and could last for decades. Integrating social acceptance into the planning of energy projects is necessary to lower the risks, while it is normally hard to assess the future acceptance of energy consumers for different sustainable energy solutions. It is because a great number of driving forces could cause changes in the trends of future developments, which makes it hard to forecast the possible public attitudes. Besides, different stakeholders always have different opinions and concerns on the public accepted solutions, which causes conflicts in negotiation in the planning and decision-making phases. In Amsterdam Southeast, the public attitudes for renewable energy solutions are uncertain, which implies potential public opposition against the implementation still could occur in the future.

This research carried out a case study on sustainable heating and cooling energy systems in Amsterdam Southeast to investigate the potential issues concerning the social acceptance of renewable energy. Values, which are relatively stable factors over time, are selected as the indicators to assess the future social acceptance of local energy end-users. The possible future value changes in the local community are forecasted through scenario analysis, and the most possible future expectations of energy consumers on the heating network developments are identified. Also, through the interviews with key stakeholders and experts in energy-related fields, a more in-depth understanding is obtained for the district heating network developments in this area. By comparing the mismatches between the future public expectations concerning the critical value fulfilments and the current network designs, the potential risks in the lack of social acceptance in the future are revealed.

The outcome indicates that a LT heating solution could be more accepted by the local consumers as a result of its advantages in increasing the energy use efficiency and reducing the carbon emission, since the local community is estimated to attach more importance to environmental sustainability in the future. However, the drawbacks in current LT network designs, such as the technical lock-ins of the network and the lack of institutional design to guarantee procedural justice, require further improvement meet the public expectations.

This method also helps stakeholders to understand the design requirements of the more public accepted sustainable energy system in the future. Due to time and resources limitation, this project

only provides a long-term strategic plan for the future sustainable heating grids development through this participatory modelling. Future research could involve more pre-trained participants who can provide more time and effort to improve the quality of results further and help the stakeholers resolve problems in negotiation.

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1. INTRODUCTION

1.1. Research motivation

1.1.1. The sustainable heating system in Amsterdam

The city of Amsterdam is taking the initiative to investigate how to phase out fossil fuels with cleaner and more sustainable energy in its district heating and cooling systems, such as the residual heat from the datacenter and soil energy, and accelerate the energy transition towards a more sustainable future without causing any public opposition. Those investigations are conducted to find a proper energy solution to reduce greenhouse gas (GHG) emissions, which is required by the Paris Agreement in response to the threat of global climate change.

Amstel III is one of the pilots in Amsterdam Southeast pursuing sustainability in its future heating and cooling systems development. Understanding the possible energy transition pathways of the district heating system requires an integrated knowledge of innovative technologies, environmental sciences, economics, and management. Moreover, in the heating energy system of Amstel III, multiple stakeholders, such as the governments, energy suppliers and infrastructure providers, and energy consumers (including tenants, real estate owners, and companies), exist. Interests from different parties may potentially conflict with each other, which further adds to the complexity of this socio-technical system.

The fifth-generation district heating network

In Amstel III, a new generation of district heating and cooling system, which is based on low-temperature water at close to ambient ground temperature, is in the future energy networks construction plan of the city district. Compared with the previous four generations (Figure 1), the new system will utilize lower temperature heat at around 25 to 28 ℃, to eliminate the energy loss in delivery and reduce the investment in infrastructure, for instance, the cost of adding insulation for pipes in the ground can be saved. In the new system, distributed heat pumps will need to be installed in every building connected to the network to transfer the heating energy based on end-users' demands at different times. In summer, it will also be more efficient to use heat pumps to transfer the heat in the room into the ground than externally mounted chillers that reject the heat into hot air to cool the houses.

This new system also offers more opportunities to collect and use waste heat from different energy sources in the area, for instance, the surplus heat from datacenters or other non-domestic buildings. The aquifer thermal energy storage (ATES) system will be employed to store and extract heat or cold in the groundwater in different seasons.

By using this new system, the overall energy operation cost can be reduced, which will consequently ease the financial burden on energy end-users. Moreover, this new generation heating system can have far less GHG emissions than the previous ones, since the system mainly uses waste heat as the energy source instead of combustion that extracts the heat from burning natural gas or other fossil fuels, and the heat pumps do not emit CO2 at all. Therefore, the new system can also offer advantages in achieving environmental objectives.

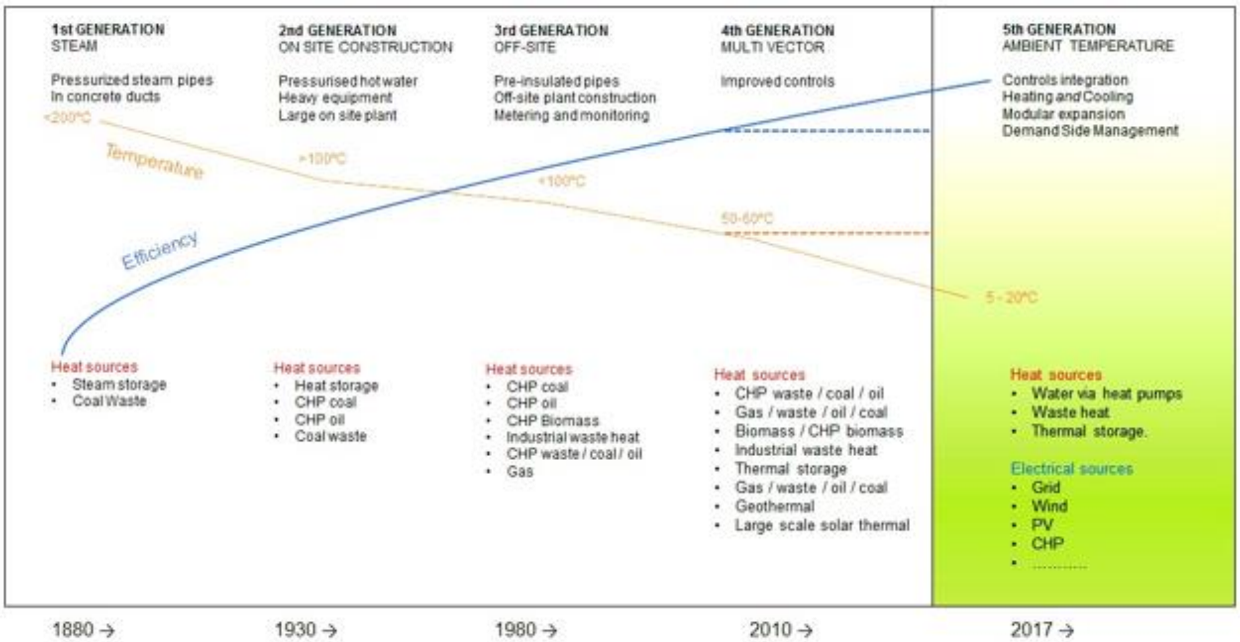


Figure 1 Heat network trends to lower distribution temperatures and higher efficiency (ICAX, n.d.)

Data heat

In the current ‘Heat Plan’ of Amstel III from the city of Amsterdam, residual heat from Equinix, which is a company that owns three data centre sites in this area, will be utilized as a renewable energy source in the low temperature (LT) heating network. This network transformation can provide many advantages over sustainable developments in Amstel III. On the one hand, the data heat can replace the energy source in the existing network in Amstel III that generates heat by burning fossil fuels and wastes, and reduce CO2 emission. On the other hand, the efficiency of energy use of Equinix, which is one of the largest electricity consumers in the area, will be vastly improved, because the residual heat from data centres will otherwise be discharged into the air and wasted. The data heat utilization plan can benefit Equinix in satisfying its cooling demands as well, especially in summer. When the nature temperature is the highest in the year, data centres will have to look for additional cooling capacity, which will consequently increase the operation cost. By offering its waste heat for free in exchange for the cooling energy from the district heating and cooling network in Amstel III, Equinix can reduce its expense for the cooling system and contribute to the low-carbon future of Amstel III.

The cooling energy supplied to datacenters will be pre-stored under the ground in the winter, which is realized by the ATES system in Amstel III (Figure 2). ATES system also makes it possible to connect datacenters with other buildings, such as the houses in residential areas and offices, to form an open-loop heating and cooling system to make use of the residual heat from data centres stored in summer.

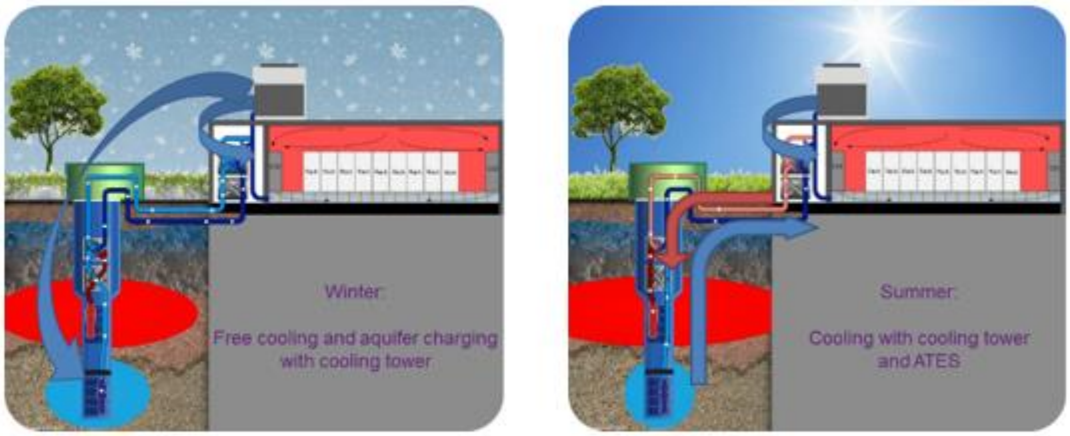


Figure 2 Aquifer thermal energy storage system (Green IT Amsterdam, n.d.)

1.1.2. Social acceptance of sustainable energy system

Although both national and regional levels of environmental policies promote sustainable energy development in Amsterdam, and innovative technologies have paved the way for the renewable energy supply, there are still numerous difficulties in realizing the energy transition. For instance, the lack of social acceptance of renewable energy technologies (RET) will cause obstacles and delays in implementing sustainable energy projects.

According to Batel et al. (2020), 'acceptance' can be defined as '*a positive attitude towards technology or measure*'. Social acceptance indicates the perceptions and attitudes of people have towards the process of the sustainable energy transition that consists of many changes in the existing energy system, such as the application of RETs, associated infrastructure construction, supporting policies formulation. It is one of the critical criteria to evaluate the readiness level of sustainable energy transition (Neofytou et al., 2020).

The study of Wüstenhagen et al. (2007) further conceptualized social acceptance into three interdependent dimensions, including community acceptance, market acceptance, and socio-political acceptance, which can be affected by influential factors and social values, such as technology innovation and distributional justice. This research mainly investigates the community acceptance related to the local neighbourhood, since energy consumers' resistance or protests can lead to significant conflicts that create more hardship in RET infrastructure construction and deployment.

Public attitude

There are various research approaches to investigate the social acceptance of specific activities that are intended to implement. For instance, Lidynia et al. (2016) employed the Knowledge, Attitude and Practices (KAP) survey model to look into the public acceptance and perceived barriers in different scenarios. Due to the available data and time limitation, the focus of this research is the role of public attitude in social acceptance.

To deploy a renewable energy system and enable sustainable living in Amstel III, some changes have to be made to the existing energy network from social, institutional, and technological perspectives. However, for every change, there will be a potential risk in leading to social resistance. For instance, replacing the existing network requires extra investment. Local inhabitants could worry that they will eventually afford this additional cost in the form of increasing energy prices and thus oppose the implementation of RETs projects.

According to European Commission (2019), most Dutch citizens (74%) believe that 'climate change' is one of the most serious global challenges, and 71% of inhabitants tend to let the Dutch governments take the lead in coping with climate change issues. Although a relative majority is willing to make changes to tackle climate change through purchasing household appliances for higher efficiency in energy consumption (72%) or better insulating their houses to reduce energy loss (37%), not everyone is willing to support this energy transition because of the extra costs and discomfort that is caused by the sustainable energy infrastructure installations.

Therefore, the changes to the existing heating network in Amsterdam could potentially cause public opposition to the development of RETs. One example is the 'Not in my back yard' (NIMBY) reaction of residents, which is a phenomenon that describes their preference to let RET infrastructure be built farther away from them and have fewer interruptions of their lives. Potential public resistance shall be identified during the planning phase of sustainable initiatives, and feasible solutions shall be developed to mitigate the impacts from those oppositions. Otherwise, the implementation of renewable energy systems could be affected (Batel, 2020). Therefore, it is crucial to understand RET's social acceptance in advance to design better energy networks that satisfy local energy users' requirements. The acceptance of local inhabitants towards renewable energy highly depends on their trust and preferences towards different designs and solutions. There are already many social resistances against some specific sustainable energy options in Amsterdam Southeast. For instance, the public opposition against the use of biomass energy in this area. This resistance was caused by the mistrust and misunderstanding of local inhabitants about the environmental impacts of biomass energy, and eventually, it obstructed the further development of biomass energy in this area.

The requirements from different types of energy users are various and therefore could be hard to satisfy. For instance, an acceptable energy network for the public shall always have sufficient heating and cooling capacities to meet the demands of different end-users in the area. However, the cooling energy demand from offices at a specific time of a day can be higher than average, which puts forward higher requirements on the energy supply of the network. There is a lack of suitable indicators of social acceptance of sustainable energy options that consider the specific needs of energy consumers. It is still uncertain which sustainable energy solutions that the local energy end-users in Amsterdam Southeast could support or accept.

Potential risks in the case of Amstel III

According to the National climate agreement (2019) from the Dutch government, 49% of the Netherlands' GHG emissions shall be reduced by 2030, compared to 1990 levels, and 95% shall be reduced by 2050. The energy sector plays a vital role in realizing this goal of GHG emissions reduction. Following the National climate agreement, the city of Amsterdam is facilitating the transition from a fossil-based energy supply system, which is only 8% sustainable according to the standard from the government, to a more sustainable energy system in Amsterdam Southeast. The LT network that utilizes waste heat in Amstel III is one option that can help achieve sustainable development goals. However, different stakeholders sometimes have conflicting interests for the development of the network, which limits the technical and institutional design space for the sustainable energy system in Amstel III. For instance, an LT district heating solution for household space heating can increase the energy delivery efficiency and can be open to more renewable energy sources, while the suitability of LT system depends on the facilities installation (e.g., heat pump for hot tap water or shower) and insulation level of buildings. It requires a rise in the insulation standard of dwellings to use LT heat, which means only new buildings with high energy labels and existing buildings that provide sufficient insulation can join the system. This requirement could potentially reduce the commercial feasibility of the LT network, since the renovation and retrofitting of old buildings for the upgrade of the energy label will involve additional investment, which may increase the financial burden of stakeholders. The conflicting values between 'energy efficiency' and 'low expenditure' can make none of the energy network design is acceptable to all parties.

Sustainable energy development is not only for reducing carbon footprint in energy generation, transmission, and consumption, but also for making arrangements to assure a steady supply of household energy as well as a lower energy price. The traditional energy supply is realized by a centralized network (e.g., district heating network) that is currently monopolized by Vattenfall.

However, Firan, a sustainable energy infrastructure supplier, is trying to create a more open and affordable renewable energy system accessible to more inhabitants in this area. This energy transition involves multiple stakeholders such as policymakers, energy system operators, and local energy users, which have different interests in this system and add the complexity of designing a more acceptable energy network.

At the moment, the city district of Amstel III is undergoing a large scale transformation from an office zone to a residential area. The new changes will bring various requirements for the district heating system in the following years. Tradeoffs between sustainable development goals and social values will have to be made to work out a realizable energy plan for every actor in the system. How to make district heating network designs that can best satisfy the requirements of local energy consumers in future planning still needs to be clarified. However, public attitudes to RETs are often hard to predict because the influences that determine these tradeoffs are too complex to address.

1.1.3. Values in sustainable energy system design

The issues in the social acceptance of sustainable energy solutions do not only occur at the planning phase. Public oppositions can even happen after the deployment of RETs or in the operation phase of energy projects. It is because the future trends in social developments continuously bring new requirements for energy services. For instance, increasing public environmental awareness affects the preference of people towards different energy options. Renewable energy networks with more public supports will probably replace the less environmentally sustainable system in the future. This potential change in public attitude shall be taken into consideration in the long-term plan of sustainable energy projects. Otherwise, issues concerning social acceptance could occur in every stage of a sustainable energy development project.

In this research, values that are of great importance to local energy users are selected as factors to assess the future social acceptance for long-term planning of sustainable heating development. The definition of the term 'value' can be '*what people care about, and it is the driving force for people's decision-making*' (Keeney, 1996, p. 3). The following reasons support this choice:

First, the duration of an energy project could last for decades, from planning to implementation. This long time horizon creates more uncertainties and makes social acceptance of sustainable energy hard to anticipate. Therefore, values that are relatively stable over time can be used as indicators to assess future public acceptance. Sometimes the characteristics of local inhabitants in a specific area can change significantly in several years due to city district transformation, immigration, or other external reasons, while values that are used as factors to reflect their attitudes to energy services will remain consistent.

Second, social acceptance issues may occur when local stakeholders feel that their values are not fulfilled. The work of Hofman (2015) suggests that unfulfilled values might arise social resistance against the attainment of goals regarding developing sustainable energy. He took the case of wind farms in the Netherlands as an example to show how public opposition against renewable energy happened when the local population found unfairness in the deployment of the wind turbines and corresponding adverse effects (e.g., noise). Besides 'Unfairness' caused by the lack of end-user involvement in the planning stage, another four values were also presented in his article as factors that could influence public attitudes.

Furthermore, the interdependencies of values can lead to changes in the importance of different values, which could reveal the potential risks in the lack of social acceptance in the future. For instance, in some cases, not all the values can be fulfilled at the same time by available options. Value conflicts persistently exist in engineering design, which increases the difficulties in making design choices (Van de Poel, 2015). The utilization of LT heating energy in Amstel III will require installing additional household appliances for some old buildings, such as distributed heat pumps and insulations, which may reduce the comfort of houses. These conflicts can influence the priorities of values for the public, which can be used to evaluate the impacts of different values on social acceptance and provide guidelines in making tradeoffs among different values in system designs for a more accepted energy solution for local end-users.

In the study of Milchram et al. (2018), a systematic literature review was conducted over 49 academic articles to identify the embedding values in smart grid design, such as privacy, security, control, and autonomy. Some of these values (e.g., the security of supply) have positive impacts on the social acceptance of smart grid, while the others (e.g., privacy) influence this process negatively, which implies that values can be either driving forces or barriers for the social acceptance of RETs, and can affect the technical and institutional designs of energy network in the planning phase.

Different energy consumer groups have different perceptions of values. It is because each of them has his/her assessment criteria for acceptable energy solutions. For example, households with lower annual income can be more sensitive to the energy price, while the users from high-income groups may care less about the cost and pay more attention to the environmental sustainability of energy sources. In this example, 'Household income' acts as an exogenous factor to public perceptions of values and influences the tradeoffs that people tend to make among different energy options.

Moreover, values perceptions for energy users to renewable energy solutions may change over time due to divergent tendencies of future developments (such as the population expansion and the increase in household income), which has a potential risk of influencing their acceptance of sustainable energy options. For instance, the unemployment rate may rise during the COVID-19 situation, which makes it harder for low-income groups to afford the energy bills, and eventually, the energy designs that require more costs (in both energy price and household appliances) will be probably opposed.

Those attributes all add to the complexities in the evaluation of public acceptance of different sustainable heating solutions and shall be taken into consideration in the sustainable network development planning.

1.1.4. Knowledge gaps

Heating energy network is a complex socio-technical system since it involves a wide diversity of technical and institutional elements and multiple stakeholders, which means every change of system has to be planned and implemented carefully. Otherwise, the changes may lead to public oppositions towards the local sustainable energy projects and hinder the implementation of more sustainable city district construction initiatives. Therefore, the interests of local stakeholders, especially energy end-users, shall be taken into consideration to design the energy network that can be more accepted by the public.

Currently, only a few inhabitants are living in Amstel III. Most of them are college students that are attracted to this place by the low rent. It is estimated that more people will move to this area, and around 10,000 extra houses will be built here for living and relaxing in the next 20 years (Maduro, n.d.). The attitudes that the future inhabitants have to different sustainable energy options are hard to forecast, since the energy user communities with various characteristics may have different perceptions towards RETs, which could also change in the long time horizon for energy project development. However, it is still essential to consider the acceptance of local people in long-term planning to avoid potential oppositions against the deployment of sustainable energy networks in the future.

Investigations on social acceptance of RETs

Many previous studies have already explored feasible solutions and technologies (e.g., ICT systems application in environmental monitoring and assessment), which can be used for pushing their energy systems towards more sustainable paths, as a result of the significant increase in GHG emissions and sharp growth in urban energy consumption (Østergaard & Maestosi, 2019). However, few design-oriented research looked into future public acceptance of regional renewable energy solutions.

In some studies, public opinions on different RETs, such as trust and preferences, were investigated through questionnaire-based surveys on a sample of respondents (e.g., Čábelková et al., 2020, Jung et al., 2016). Their works reflected the attitudes of local stakeholders of sustainable energy networks within a particular region (e.g., a metropolitan area or a country), and provided recommendations on technical and institutional designs of energy network to improve the social acceptance of RETs. For instance, the individual owner based subsidies for the detached houses of the energy network. However, they did not further explore how the social and moral values may change over time that can affect the public attitudes to RETs implementation.

Making design choices for sustainable networks and investing in RETs requires strategic analysis and long-term planning based on good quality social and scientific research. It is because the complexity and long lead times for energy projects (e.g., resources exploration) bring uncertainties and risks in multiple forms, such as institutional and regulatory risk, technical lock-in, as well as resource risk, which is especially significant for soil energy (IRENA, 2016). According to the research of Nikas et al. (2018), the Netherlands is not expected to meet its 2020 renewable energy target and respective commitment as a result of public opposition that increases the uncertainties about societal nature in sustainable energy projects implementation. Nevertheless, little attention has been paid to the role of social acceptance in the planning for sustainable energy development. Cuppen et al. (2019) investigated the societal conflicts used to analyze the plans for energy transition at the higher policy-making level, whereas there is still little concern regarding the value conflicts that result in the lack of public acceptance. The work of Boijmans et al. (2019) employed agent-based modelling (ABM) approach to identify the value conflicts that could lead to criteria dilemmas for the moral acceptability of decentralized energy systems in 'De Vruchtenbuurt', The Hague. Although the interdependences of the entities of interest are represented in their research to identify the design requirements for more acceptable energy solutions, long-term trends for sustainable energy developments were not discussed.

The investigation of public acceptance of the renewable energy solution is seldom integrated into the long-term plan for sustainable heating system development. However, for the case of Amstel III, it is necessary to anticipate the future social acceptance in the planning phase, which is insufficiently addressed in the previous research.

Transition pathways towards sustainable energy

The scenario analysis method has been widely used in the field of energy economy planning since its emergence. Besides quantitative modelling (e.g., ABM), many other scenario planning approaches have been applied to deal with the long-term decisions and uncertainties in sustainable energy transitions as well.

Broll et al. (2020) employed a two-stage approach to derive consistent energy scenarios based on critical causal relationships of exogenous drivers for future developments. The scenarios constructed in their research contain driving factors with various main focuses, whereas there is a lack of consideration from the public acceptance perspective. For instance, the perception of local inhabitants is neglected in their research. Weimer-Jehle et al. (2020) conducted a comparative analysis of the application of the Story-and-Simulation approach in constructing energy transition scenarios through a comprehensive literature review. Their research outcomes indicate that, although energy scenario is a suitable tool for analyzing the dynamics of the sustainable energy transition, little previous research has employed it to investigate the role of social acceptance, particularly from the perspective of local inhabitants, in the implementation of RETs projects.

In sum, the previous research is insufficient to address the lack of social acceptance of sustainable district heating systems in Amstel III, which requires the anticipation of public attitudes to RETs project that have a long-range planning horizon.

1.2. Research problem

1.2.1. Research objectives and scope

In the last section, knowledge gaps in research on social acceptance of sustainable energy system designs have been identified. Insight on the integration of social acceptance anticipation and long-term strategic planning for sustainable energy development is still absent. This research aims to *assess a potential future lack of social acceptance of sustainable energy systems by evaluating how values may change over time*. This aim is to gather design requirements of a more accepted energy network for energy consumers in Amsterdam. Due to the limitation of resources (e.g., time and effort of workshop participants) and time constraints of this project, the research boundary is set only to investigate the sustainable energy solutions within a specific city district: Amstel III. There are three major types of energy demand in the area, including electricity, hot water, and space heating. In this study, district heating and cooling network is the main focus. This research explores how the importance of four selected values (section 4.1) for the public, which are used as the criteria to assess the social acceptance, may change in the energy transition processes, as a result of the complex interdependencies of exogenous and endogenous system factors. The scenario analysis approach, particularly the Cross-Impact Balances (CIB) method, is employed to forecast the plausible future developments. Further details on this method will be introduced in Section 2.

Following this aim, the objectives of this research are formulated:

First, which factors could lead to the value change in the future are uncertain. This research is intended to investigate the influences of different types of factors, such as characteristics of inhabitants and local conditions, on the social acceptance assessment criteria.

Second, this research will try to forecast the possible future concerning the value changes in the heating energy system of Amstel III through a scenario analysis approach. By comparing the plausible future developments in this area with the current designs for the future sustainable energy network, potential issues that are related to pubic acceptance can be identified.

Last but not least, based on the outcomes of scenario analysis, corresponding recommendations to improve the social acceptance of district energy transition for Amstel III shall be provided.

1.2.2. Research questions

The main research question is presented as follows:

"How can the future social acceptance of sustainable heating systems be assessed and improved for a city district's long-term development plan in Amstel III?"

Four sub-questions are also proposed to have a better interpretation of the main research question:

1. **What are the critical system elements in district heating networks that can influence the fulfilment of public acceptance assessment criteria?**

This question is to identify the set of driving forces that have impacts on the value changes. This set will contain two types of elements. One is the exogenous factors that shape the future development of sustainable energy projects. For example, the stricter building law in Amsterdam next year (BENG standard) will force all old buildings in this area to obtain a higher level energy label through renovation or retrofitting. This type of factors will be considered as external constraints that influence the casual relationships among scenario elements. The other factors have more interdependencies with public perceptions of values (which are used as social acceptance criteria in this research), and represent the local conditions. For example, the CO_2 reduction is related to the importance that local energy users attach to the value 'Environmental sustainability'. The factor selection is accomplished through semi-structured interviews with experts and stakeholders, and the processes will be introduced in Section 4 with more details.

2. **How to specify key system factors in scenario analysis models?**

System elements and their interdependencies shall be interpreted and conceptualized to construct scenarios used to forecast the future developments of sustainable heating energy in a specific area based on the internal consistency of scenarios.

3. **What are the most plausible future scenarios for the social acceptance of sustainable heating solutions?**

The scenario analysis approach, particularly a Cross-Impact Balances (CIB) matrix, is employed to anticipate the potential lack of social acceptance in different heating system designs due to value change in the future. The algorithmic method of CIB can combine qualitative and semi-quantitative data to remove inconsistent scenarios based on the causal relationships among system elements and reserve the consistent scenarios that reflect the most likely future developments.

4. What are preferable designs for a district heating and cooling network?

Plausible future developments provide recommendations for sustainable network designs in terms of improving social acceptance. Design requirements of a more accepted for energy users can be gathered through scenario analysis, which can be used in the long-term strategic planning for RET projects.

2. METHODOLOGY

The research approach in this project is an exploratory case study of the sustainable LT heating system of Amstel III with a semi-quantitative scenario analysis model, which includes two parts: gathering the insights on the technical and institutional designs in current sustainable district heating system plans through in-depth semi-structured interviews and surveys to experts in different fields, and the forecast of plausible future developments by using scenario analysis method. By comparing the outcomes from those two parts, the mismatches between the network designs and future trends in value changes can be identified, which reveal the potential issues in the lack of social acceptance of sustainable energy in the future.

2.1. Scenario analysis

To anticipate how the values used as assessment criteria for public accepted energy networks may change over time, a scenario analysis approach is employed in this research to reduce the uncertainties and investigate possible trends in the future. Scenario analysis model can help to identify sustainable energy development paths that can be more accepted by the public, and support decision-making processes concerning network and policy designs.

Scenario analysis is an approach to generate and describe plausible future developments through projection, assumption or simulation, and investigate how critical system elements and objectives can influence these scenarios. It is often used for long-term strategic planning and can be used as a tool to gain a greater understanding of sustainable energy solution foresight (Weimer-Jehle et al., 2020). It integrates the social and institutional factors that shape the energy system designs into the scenario construction, and speculate all the possible future developments of the research object. According to the study of Weimer-Jehle (2006), the scenario technique is particularly applicable for:

- which no theoretical framework is applicable to construct a mathematical model for quantitative analysis;
- whose interactions among different system elements are too complex to be straightforwardly presented in conceptual models;
- and, which no or little knowledge concerning the mathematical relationship of the components is available to express the system with quantitative formulas trustworthily.

It can combine quantitative and qualitative materials and use experts' knowledge and experience to forecast the possible future developments in a specific area. It has been used in a wide range of socio-technical systems research, such as the studies in energy and economics fields. One of the applications of scenario tools is to support the decision-making processes in regional sustainable development plans (Döll, 2004), when the impacts that decisions have on future district developments are quite uncertain and unpredictable, owing to the lack of detailed source of information regarding the characteristics of the research object, as it is presented in Figure 3.

A scenario can be used to describe the possible future developments in a specific city district. It consists of elements that can reflect the features of the area, such as household income, education rate, age groups, et cetera. Those elements may have complex casual relationships with each other, which is hard to be clarified. Scenario analysis is a tool that can help to provide a clear image of the future development possibilities. Some influential factors for the area will determine those future developments. For example, in the case of Amstel III, the determinant factors could be environmental awareness of local inhabitants and legislation. When local people care more about climate change, and environmental regulation becomes stricter for energy suppliers, then the most possible future could be a zero-carbon city.

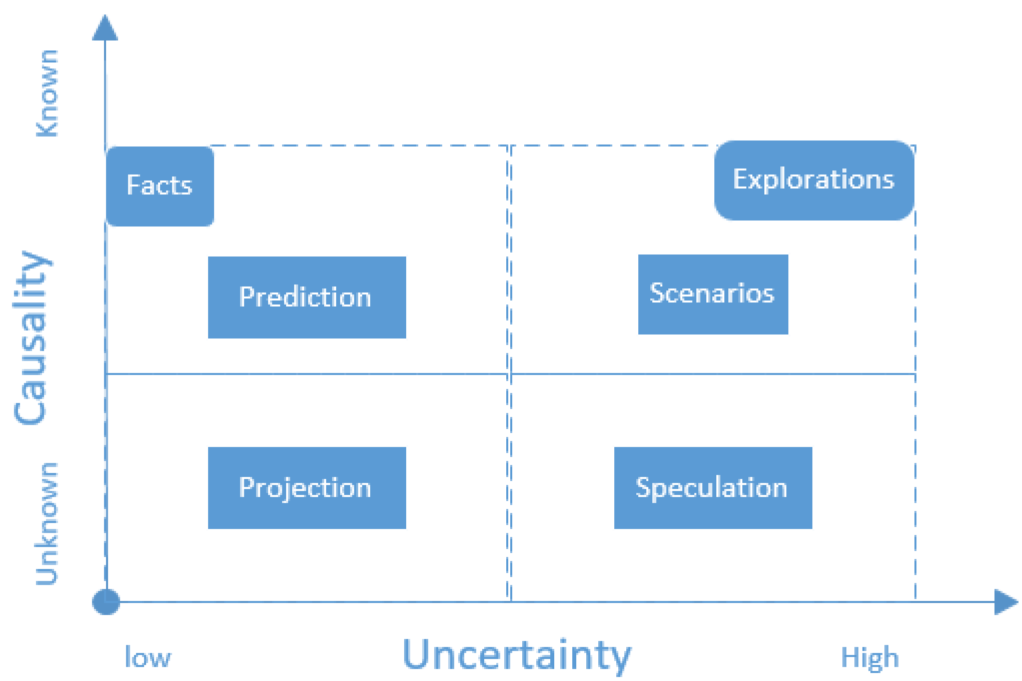


Figure 3 A comparison of forecasting tools

In this research, a scenario analysis approach is employed to explore the future social acceptance of two types of heating network designs (i.e. the existing district heating system and the LT energy delivery system) in Amstel III, and by investigating the relationships of key system elements and the consistency of each future scenario, the most likely future developments in local renewable heating energy networks are identified. Those scenarios will be used to investigate the possible future social acceptance of local energy users towards different network designs from technical, institutional and commercial perspectives, and provide insights concerning how to improve their acceptance for the renewable energy transition.

2.1.1. Scenario planning techniques

Scenario techniques encompass a diverse range of qualitative and quantitative research activities (Thomas, 2012). Each approach has its advantages and limitations in strategic planning.

Quantitative model

Mathematical modelling, which is well-defined with mostly quantitative components, is suitable for future developments projection only when the lack of some incomputable components of the research system and the limitation of incomplete uncertainty understanding of the problem will not impact the quality of research outcome and are acceptable for researchers.

Purely quantitative prediction models based on historical data have limitations in dealing with future uncertain developments and making long-term plans. An enormous number of elements and affecting factors are involved in scenarios for the city district's future sustainable development, which leads to an increase in system complexity and uncertainty. For instance, city district transformation brings uncertainties with regard to houses building, infrastructure investment, energy consumption, and local mitigation and adaptation strategies in response to climate change. Quantitative methods have strict criteria with the input data and internal values for mathematical computation, while, in some cases, credible information and concrete data may not be available, which implies quantitative models are not suitable to represent some specific system elements in the conceptualized scenario. Besides, when the time horizon becomes more prolonged, and the complexities correspondingly grow, the outcome of quantitative models tend to be less reliable. Therefore a purely quantitative approach may not be the best choice for anticipating future social acceptance of sustainable heating network in city districts, since most of the energy projects involve long-term investment and implementation.

Qualitative approach

Qualitative scenarios are often combined with storylines, highlighting vital scenario characteristics, relationships between main driving forces and system dynamics, to logically and clearly forecast the potential future. For instance, the Special Report on Emissions Scenarios (SRES) is used to explore future developments in the global environment with particular reference to greenhouse gas production and aerosol precursor emissions. Based on the future trends of system driving forces included in scenario construction, four qualitative storylines were developed to present the different demographic, social, economic, technological, and environmental developments of the system in the future. As shown in Figure 4, those storylines are like branches of a tree (system), which represent divergent future directions of scenario tendencies. Scenarios provide an interpretation of the possible future in a specific research field and support the planning for further developments.

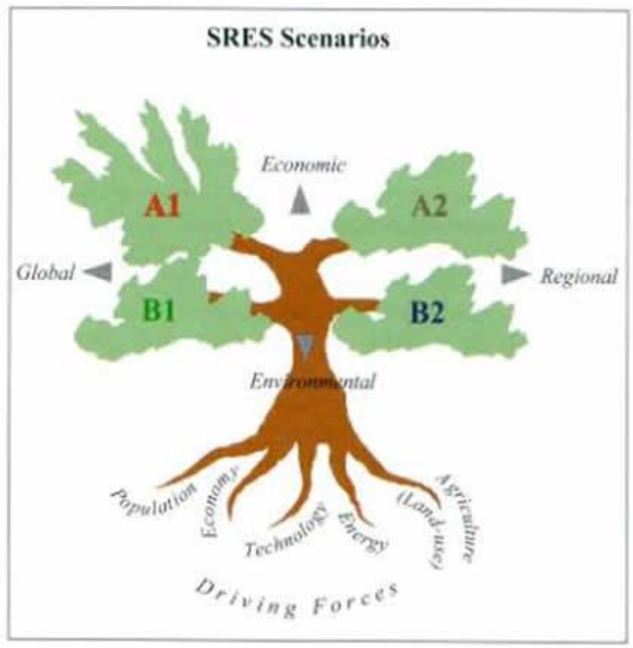


Figure 4 *SRES* Storylines (IPCC, 2019)

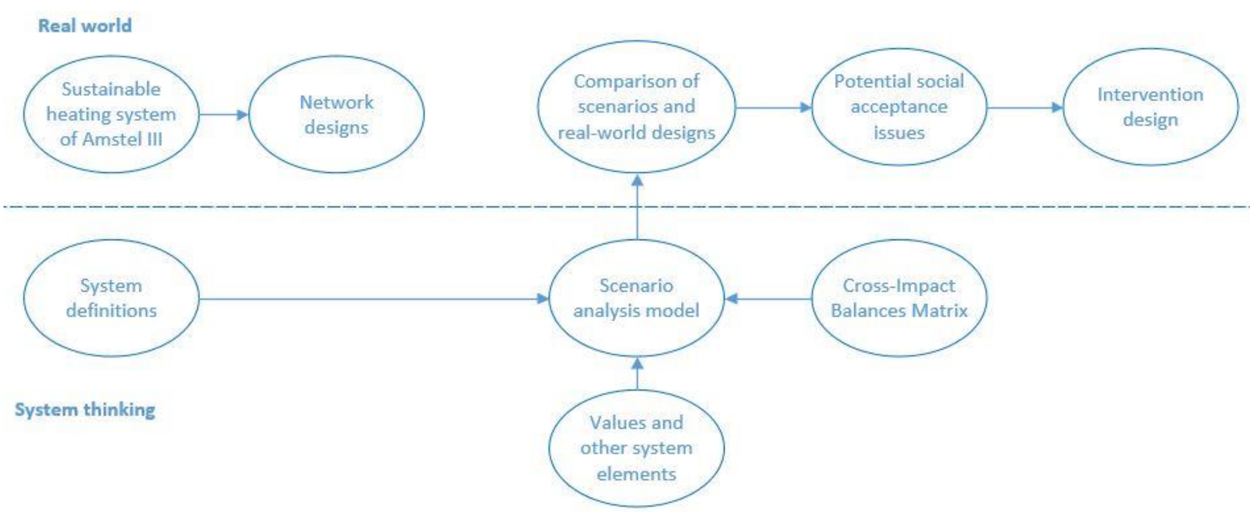
Qualitative scenario analysis can be used to include different views with respect to future development trends. However, the interpretations in qualitative storylines are highly dependent on the subjective judgments of experts who participate in scenario analysis (Rounsevell & Metzger, 2010). Moreover, the qualitative scenario constructions can be restricted by the lack of knowledge and experience.

To summarize, the interactions among different system components are too complex to be captured by purely quantitative models that often have assumptions to oversimplify the system to meet calculation requirements. It cannot precisely describe the system with high uncertainties and will lead to less practical results. Moreover, qualitative analysis along cannot reduce the subjectivity in anticipation of future trends. Therefore, a scenario analysis approach that combines qualitative and quantitative scenario components and considers a number of possible future developments and events to deal with uncertainties, is preferred as the tool to explore the value change in sustainable energy designs over the long term.

2.1.2. Cross-impact balances

Cross-Impact Balances (CIB) is a method that can construct qualitative and semi-quantitative scenarios systematically (Weimer-Jehle, 2006). These scenarios consist of combinations of different states of system elements. It helps to clarify the dependencies and relationships among different system elements by collecting pair-wise quantitative judgements from experts elicitation and literature review. It is also used to check the internal consistency in the explorative scenarios (Börjeson et al., 2006). Based on the self-consistency scores, most likely future developments can be identified.

Compared with ABM, which highly depends on initial conditions and not suitable for long-term strategic planning, CIB as a participatory planning approach particularly fit for exploring future trends in a specific area based on the complex causal relationships among system factors. Weimer-Jehle et al. (2020) suggest that CIB analysis not only provides plausible scenarios, but also acts as a database that contains the knowledge of experts in terms of critical relationships between two system factors. Due to the advantages of CIB in improving the traceability, reproducibility, consistency, and comprehensiveness of storyline construction, it has the potential in better integrating the storylines of socio-technical scenarios with conceptual scenario models in research with a wide range of disciplines, such as climate change and energy transition.



Conceptual model of Soft System Methodology

2.2. Data collection

In this research, a comprehensive literature review is conducted to collect information for the case study of the sustainable heating system in Amstel III. Besides, semi-structured interviews, questionnaire surveys, and focus group discussion (workshop) are used as data collection tools for gathering judgements and insights for research topics. However, most participants of those activities are experts in energy-related fields, only two representatives of citizens are invited to the interviews. This absence of widespread citizen involvement is due to two reasons: 1. The judgement collection session of CIB matrix construction requires professional knowledge and experience of experts in relevant fields; 2. It is estimated that the characteristics of the local population in Amstel III will change dramatically in the following years (e.g. more new residents will move to this area), which makes the attitudes of current inhabitants less representative.

Literature review

Improving the social acceptance of renewable energy remains a longstanding challenge in urban sustainability development. Toward this objective, this study explored possible future developments by employing scenario analysis techniques. Professional knowledge and concrete data are desired inputs for constructing scenarios that can best describe the system in this study. A systematic literature review is performed throughout this research to collect relevant information regarding characteristics of city districts, determinant factors that influence social acceptance, and critical techniques in constructing scenarios. Most of the information is retrieved from scientific publications on sustainable energy development and public acceptance research, and online open data from governmental organizations, such as CBS and the European Commission.

Interviews and surveys

Besides the literature review, interviews with experts from different sectors are conducted to gather insights and information regarding local energy grids development. There are several rounds of semi-structured interviews for qualitative data collection for this research, which serve different research requirements in different phases of this project. These interviews help to understand the future sustainable developments in the heating and cooling system in Amstel III. The participants also verify the values used as social acceptance assessment criteria as well as their interdependencies. These contributions are used to construct scenario models (section 4) and identify the plausible future concerning the value changes in the area.

A questionnaire-based survey is also used as an alternative approach, since some participants do not have sufficient time for a complete interview, which may take 1 hour to finish. Those two data collection methods have their own advantages in expert elicitation and complement each other in this project to create the best possible results (Figure 5). Table 1 and 2 present the interviewees that participate in each round. The questions that are used in interviews and survey can be found in Appendix F.

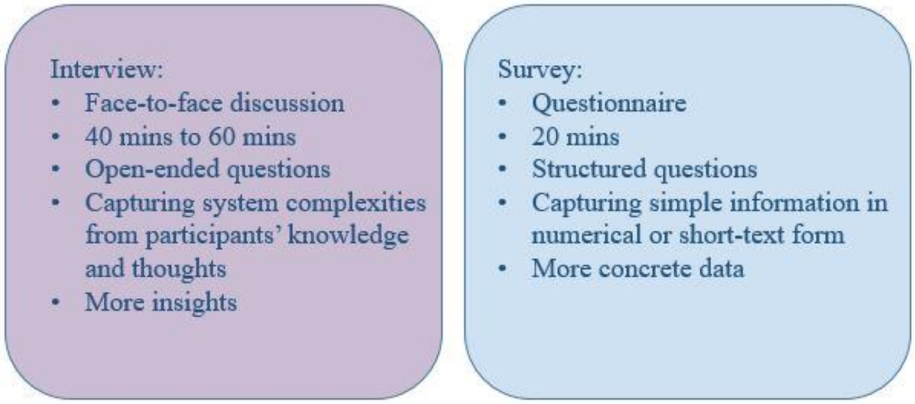


Figure 5 A comparison of interview and survey

2.2.1. Orientation

The first round of interviews and surveys are conducted for a deeper understanding of the sustainable heating network developments in Amsterdam Southeast. Future opportunities and planning (e.g. governance model), potential obstructions and conflicting interests among different parties are discussed in this phase. Moreover, values that can best assess the social acceptance of local inhabitants towards the sustainable heating grid and collect the determinant factors that influence the fulfilment of values, are clarified by the participants.

Four types of interviewees are invited to participate, including policymakers from municipality, energy system operators who participate in the deployment and operation of the sustainable heating grid, project initiators who provide expertise to support the feasibility study and decision-making of sustainable energy solutions, and local inhabitants in Amsterdam Southeast.

Table 1 Participants list of the first round interviews

Interviewee	Organization	Role
Policymaker 1	Municipality of Amsterdam	Spatial Planning Department
Policymaker 2	Municipality of Amsterdam	Energy and Circular development
System operator 1	Equinix	Principal Engineer
System operator 2	Waternet	Consultant Energy, Resources and Water
Project initiator 1	AMS. Institute	Program Developer at Urban Energy Research & Valorization
Citizen 1	ZO!City	Advisor at Quality of Life Researcher
Citizen 2	CoForce	Project leader of CoForce Foundation

The outcomes of these interviews also provide inputs for constructing scenarios that describe the value changes for sustainable heating energy in the context of city transformation. Due to the limitation of time and available contacts, only seven experts in energy-related fields participate in this section. More participants are expected to join this discussion to share their insights in future research, which can improve the set of values and determinant factors iteratively.

2.2.2. Judgements collection

The second round of interview is expected to use the professional knowledge and experience of interviewees to provide their understanding of the causal relationships between system elements. These judgements are then used to examine the internal consistency of scenarios that represent the potential value change over time for local energy consumers in Amstel III, and identify the most plausible future situations.

To make more efficient use of the available time of experts and enable their discussions to gather more insights, a workshop is held during a meeting at the city of Amsterdam that is for exploring the approach to achieve natural gas-free future in Amsterdam. This event involves the energy sector experts and employees from the municipality (including the department of R&D and G&O) as well as Waternet. The details of this workshop, as well as the contributions of the workshop to the scenario analysis model of this research, are presented in section 4.3 and Appendix D.

2.2.3. Validation and verification

The most likely futures for the public acceptance of the sustainable heating network can be identified through scenario analysis. In the third round of interviews, research results are discussed with experts in relevant fields. Experts' statements are used as a validation tool to test if the outcomes of scenario analysis comply with the real-world requirements, especially concerning the possible risks of unfulfilled values in the current sustainable energy solutions in Amstel III. The insights gathered from this step can help identify the mismatches between the possible value change in the future and the heating network designs. These mismatches can reveal the potential lack of social acceptance and provide references and hints for designing more accepted sustainable heating grid for the energy consumers in Amsterdam.

Table 2 Participants list of the third round interview

Interviewee	Organization	Role
Policymaker 2	Municipality of Amsterdam	Energy and Circular development
Project initiator 2	IF Technology	Senior Energy Concept Developer
System operator 3	Vattenfall	Business manager
System operator 4	Firan	Senior business manager
Citizen 1	ZO!City	Advisor at Quality of Life Researcher

Figure 6 provides an overview of how the future social acceptance of sustainable energy solutions is assessed by identifying the mismatches in system design requirements concerning the value fulfilment and the future situation and trends in the network development.

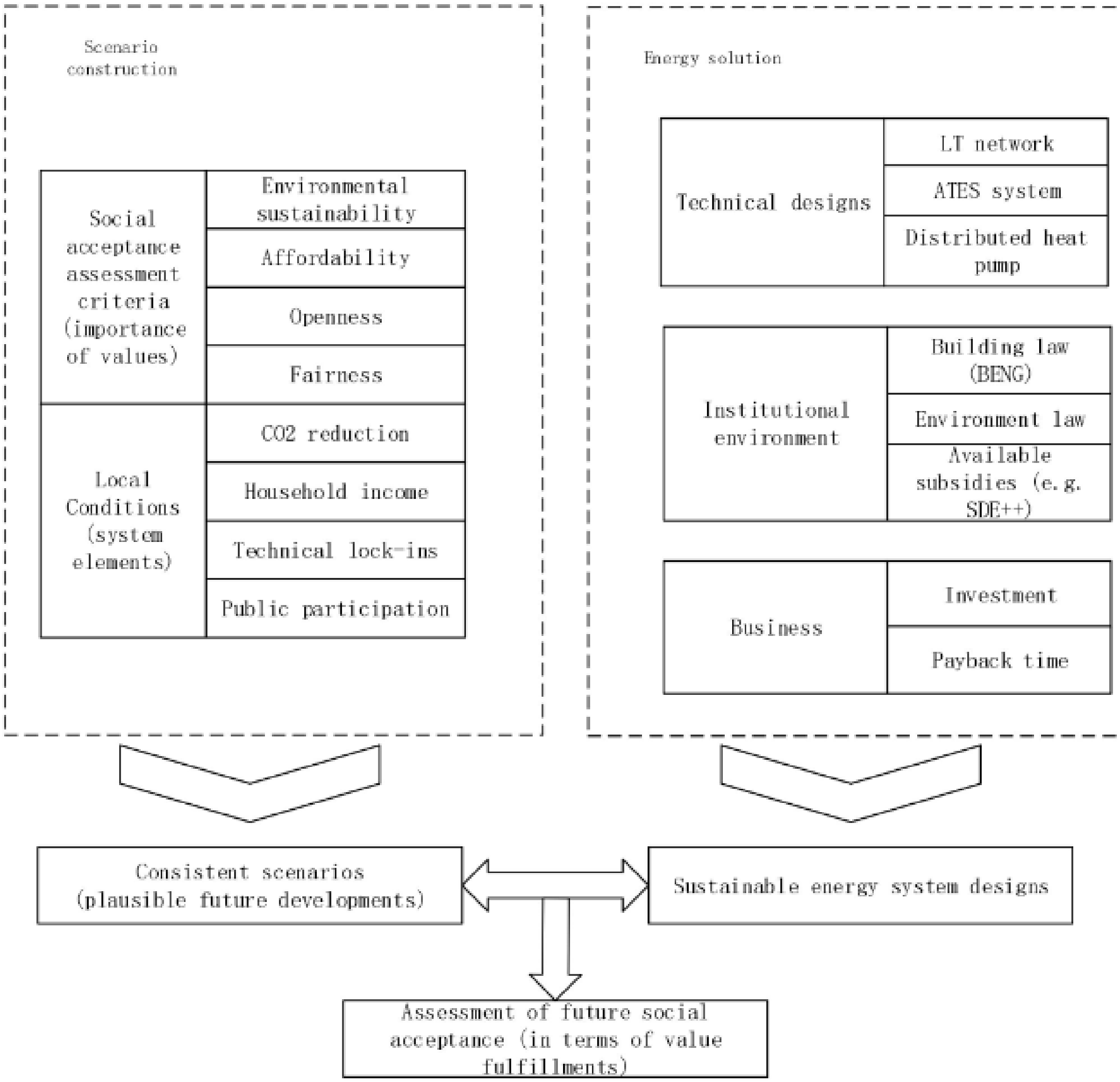


Figure 6 Future social acceptance assessment

3. DESCRIPTION OF SUSTAINABLE HEATING SYSTEM IN AMSTEL III

This chapter provides an introduction to Amstel III and its redevelopments. Future opportunities and potential risks for sustainable energy developments in this city area are also presented to understand technical and institutional designs in current sustainable heating network development, as well as the complexities in the project planning and implementation processes (e.g., stakeholder engagement). Most of the information and findings in this section is obtained through the semi-structured interviews and online open data.

Figure 7 Landscape of Amstel III city district (in the white line)

3.1. Redevelopments in Amstel III

3.1.1. Local conditions

Amstel III is the largest business district located in Amsterdam Southeast (Amsterdam-Zuidoost), which was developed in the 1980s and now provides approximately 250 hectares space to enterprises, stores, restaurants, utility buildings. Around 2040 companies with a wide range of types have established their headquarters or branches here. More than 26% of them are real estate companies or financial service corporations, and the business services companies occupy the same proportion. Trade and catering business account for 23%. About 13% of companies are from information and communication technology sector. For industrial firms and energy companies, the proportion is 7%, which is comparatively low. Companies in culture, recreation and other services industries make up only 4% (CBS, 2019).

Due to the regional orientation of this business area, the number of inhabitants in Amstel III is relatively low. According to statistics, the number of households in the area is no more than 565 by 2019. The population density of Amstel III (143 inhabitants per km²) is also far less than other city districts in Amsterdam. Figure 8 depicts the layout of neighbourhoods in Amstel III and the current population density of each neighbourhood on the map. Other characteristics of inhabitants in Amstel III are specified in Appendix B.

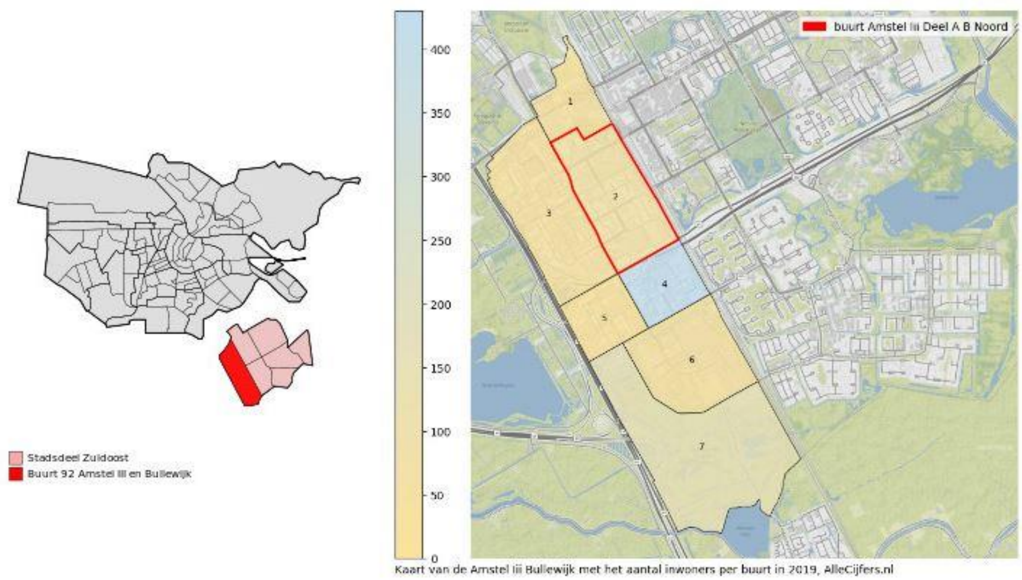


Figure 8. The map shows the following neighborhoods: 1: Hoofdcentrum Zuidoost neighborhood, 2: Amstel III neighborhood Part AB Noord, 3: Amstel III neighborhood Part CD Noord, 4: Amstel III neighborhood, part AB South, 5: Amstel III neighborhood, CD South, 6: Amc neighborhood, 7: Hoge Dijk neighborhood. (AllCharts.info, 2019)

3.1.2. Transformation in Amstel III

A number of vacant offices emerged in the area a few years ago as a consequence of economic change, which made Amstel III one of the regions with highest vacancy rates (approximately 30% in 2011) in Amsterdam (Dekker et al., 2018; Environmental Data Compendium, 2016). In recent years, the city of Amsterdam is taking the initiative to transform this business area into a city district with a mix of use for people to work, live and relax. Versatile functions have been added to this place, such as entertainment, shopping, healthcare, technology innovation, and education, which boosts the vitality in this area and also increases its attractiveness to innovative companies and startups. More lands in Amstel III will be turned into livable places for inhabitants in the coming years. According to the future development plan of the municipality, around new 5,000 homes will be built here before 2027, and from 2027 to 2040, another 10,000 homes are expected to be built (Gemeente Amsterdam, 2017). Moreover, some vacant office spaces will be converted into residential places as well. For example, the transformation of Trinity Buildings in Amstel III (Gemeente Amsterdam, n.d.) shows potentials in creating livable residential spaces for new inhabitants.

The transformation in Amstel III involves not only the demolition and replacement of old buildings, but also the reconstruction and renovation for new ones. In this redevelopment, many new opportunities have been created for sustainability development initiatives and research projects to integrate their goals into the construction objectives of buildings and closely collaborate with property developers in these processes, since, in most cases, extra infrastructure is desired to satisfy some specific requirements of sustainable development. For instance, by adding additional insulation to houses, the energy loss can be reduced, while this may cause extra construction cost. Moreover, the participation of different parties, such as energy network operators, housing corporations and municipalities, in the planning phase increases the chances of successful implementation of sustainable development projects. The housing corporations can also make use of the momentum from these renewals to make the district sustainable and help create affordable natural gas-free systems (Meijer, 2020). For example, the case of ‘Bloemenbuurt’ (Schaart, 2020) illustrates how successful collaboration among municipality, infrastructure operator, and housing corporations in rebuilding the city district helps to redesign the heating networks in the area and find feasible energy option for local end-users.

Despite the new changes from urban renovation, the inherent dynamics of this transformation will inevitably increase the uncertainties in the future development of city district, which adds more complexities to the feasibility study in sustainable development initiatives, and hinders the progress in implementing sustainable energy systems in the area. For instance, as more and more new inhabitants move in, the difficulties in achieving consensus on some specific sustainable solutions will consequently increase. One of the controversial issues is the utilization of biomass energy. There is already much social resistance against using bioenergy as a renewable source in Amsterdam southeast (Policymaker 1), because not everyone trusts the sustainability of this type of energy source. It is expected when more people are allocating to this area in the following years, the intensity of this debate will consequently increase as well.

3.2. Energy transition designs in Amstel III

To reduce GHG emission to create a more sustainable environment and meet EU standards, the city of Amsterdam intends to speed up the process of its energy transition. The transformation of Amstel III brings opportunities as well as new requirements for sustainable energy development in this area. For instance, the construction quality of buildings can severely restrict the design choices for energy networks (System operator 3). In general, there are three primary energy use domains for households: electricity, hot water heating, and space heating and cooling. In this research, electricity grids are not included in the scope. This research focuses on future developments of district heating and cooling networks in Amstel III, which often involve long-term investment decisions for local stakeholders and are less flexible than the electricity grid. The municipality aims to achieve a future scenario that fossil-free heating and cooling are available for the entire city district in 2040.

In the future city district planning of Amstel III, it is estimated that 35,000 to 40,000 new houses will be built for inhabitants in the next 20 years (until 2040). Currently, only approximately 1,500 college students are living there as a consequence of the ongoing city transformation. The future trend in Amstel III concerning the landscaping plan will be a mix of office zones and residential areas, and different areas have different building criteria that are regulated by the heating law. For instance, according to the Dutch Buildings Decree, all office buildings in the Netherlands should at least meet for energy label C before 2023, which is to realize Nearly zero-energy buildings (NZEB, and the BENG in Dutch national building law). Figure 9a presents the energy labels that each building has in the north of Amstel III. There are still some old buildings with the energy labels of D, E, F, or even G. The new energy efficiency regulation will require renovation and retrofitting for those existing buildings, especially for the buildings with label G, which will need more drastic measures, such as demolishing and rebuilding. Extra houses will also be added next to this large office area in the redevelopment in Amstel III.

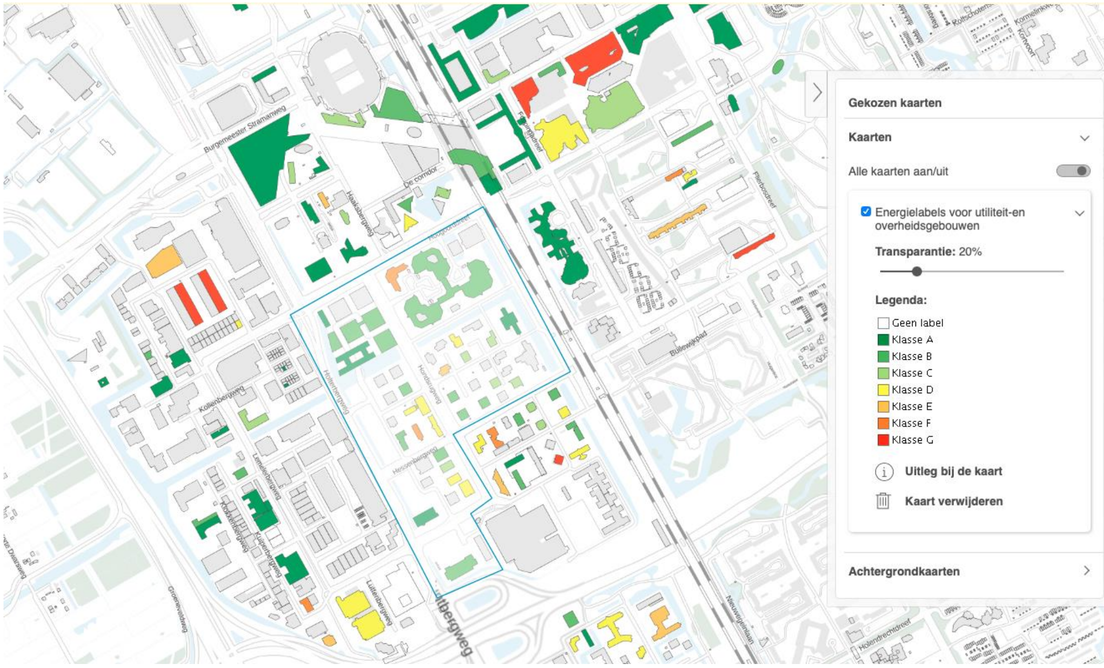


Figure 9a Current energy labels in Amstel III (Nationale EnergieAtlas)

3.2.1. District heating and cooling network development plans

There are currently several pilot projects and research that strive to explore feasible solutions to realize a more sustainable heating system in Amsterdam Southeast. There are three types of available heat sources heat in the area:

a. District heating system that is operated by the monopoly supplier Vattenfall, which comprises about 95% of the energy market in Amsterdam Southeast.
b. Utilization of waste heat from datacenters, which already has several pilots in Amsterdam Southeast that need further investigation.
c. Aquathermal energy, which is estimated to play stronger role in the future.

One of those initiatives is the utilization of residual heat from data centres in Amstel III. A tremendous amount of residual heat is generated by data centres every day, which is usually released to the outside via water or air. Equinix, which owns all the large data centres in Amstel III (Appendix C) at present, hopes to assist in the improvement of sustainability in the area, as well as increase its energy efficiency by providing waste heat to households and other buildings in Amstel III for free. In exchange, these data centres will receive cooling energy from the district heating network. This integration of data centres and heating grids can benefit both Equinix and the city district. On the district energy system level, a reliable source of heat becomes available.

Moreover, for data centres, this is an economical way to vent out needless heat to maintain a suitable internal temperature, which can reduce its overall energy consumption. Improving the effectiveness of energy reuse also adds credits for the social responsibility of datacenter and brings it a global competitive advantage (Wahlroos et al., 2017). Residual heat reuse capability is estimated to be recognized as one of Equinix's KPIs in the future (System operator 1).

However, the changes in the societal characteristic of the area (such as population and household income level) that result from city transformation bring new challenges to the energy transition works in Amstel III. Future developments can affect heating grids with technical and business sides, and as a consequence, lead to a change in the public acceptance of different heating options and alternatives. Future scenarios determine the technical designs of the heating network, such as the temperature in pipes for heating energy transmission and heat pumps deployment. An approach that can cope with uncertainties in future scenarios shall be employed to envisage the most plausible future developments and provide corresponding recommendations to facilitate the implementation of sustainable initiatives in the area. At present, there are two types of heating networks in Amstel III:

Medium-temperature (MT) network: which mainly services for the existing office buildings in the area. It is monopolized by Vattenfall and is transformed from the previous high-temperature (HT) network, in order to satisfy the new requirements from BENG in 2020. Currently, only 8% of the energy supplied by this existing main grid can be considered 'sustainable' (Policymaker 2), since most of its heating energy is generated from burning fossil fuels and wastes. The existing HT network cannot be considered as an acceptable option in the future for the reason that it has poor performance in the Sustainability Index from the city of Amsterdam, and local house owners and property developers will oppose it. Therefore, it is necessary to connect the existing grid with more renewable energy sources. For example, the residual heat from data centres.

Low-temperature (LT) network: which will be open for more sustainable energy sources (e.g. datacenter) and supply heating energy to newly constructed houses (mostly built in 1980s) and high-rises in residential area in the future. It is because the utilizing of LT energy has more strict criteria concerning the insulation, heat pumps, and other household energy appliance that necessary renovations and maintenance of buildings are required (e.g. adding insulations to the wall and solar panels on the roof), which increase the difficulty in construction for property developers. Moreover, there still some risks of LT network, for instance, a potential higher cost. When the heat pumps do not work correctly, or the insulation of houses fails for some reasons, more electricity will be consumed, which may bring the extra cost to energy consumers. This risk can be reduced if the heating system is well designed and engineered, while in some cases commercial system operators, such as Vattenfall and Firan, do not care much about those issues. It is suggested by some government-related energy infrastructure providers (interview Waternet and Firan) that utility sectors or service company shall be responsible for the maintenance of network facilities (e.g. heat pumps) as they always have sufficient expertise for the repair work. It will cost much less for energy consumers than when they have to take care of it themselves and much less hassle.

Based on the heat plan from the city of Amsterdam, MT and LT are supposed to be interconnected with heat exchangers or heat pumps to satisfy different energy demands from different types of buildings (e.g. office buildings may demand more cooling energy). It shall ensure that the district heating system is open enough to involve more sustainable energy suppliers in the area. The energy consumers should be free to choose their energy suppliers in the future, instead of being monopolized by a commercial organization, which is a profit-oriented entity and could lead to higher and higher energy price every year.

Considering the fulfilment of social and moral values, integrating the LT network to the main grid is a more desirable solution for local stakeholders and will be expanded to more areas in Amstel III. Therefore, the investigation of social acceptance of LT energy solution in the future will be the main focus of scenario analysis in this research.

Table 3 A comparison of two networks

Designs	Energy solution 1	Energy solution 2
Type of networks	MT network (Transformed from the existing main grid)	LT networks (Integrated to the main grid in the future)
Energy sources	Waste/ fossil fuels incineration	Free waste heat from data centres + Soil energy
Subsidy	No	Several available grants
Infrastructure	One monopolist, Vattenfall	Cooperation of Vattenfall and Firan
End-users	Existing old buildings	New built houses or high-rises with energy label higher than C
Energy efficiency	Less energy loss than HT.	High efficient
Negotiation	No need	Hard and time-consuming

Figure 9b shows the deployment of the heating and cooling network in Amstel III. Net 1 and 2 are the HT and MT networks owned by the Vattenfall, while net 3 and 4 are the LT solutions from Firan with ATES suppliers, such as IF and ETEQ.

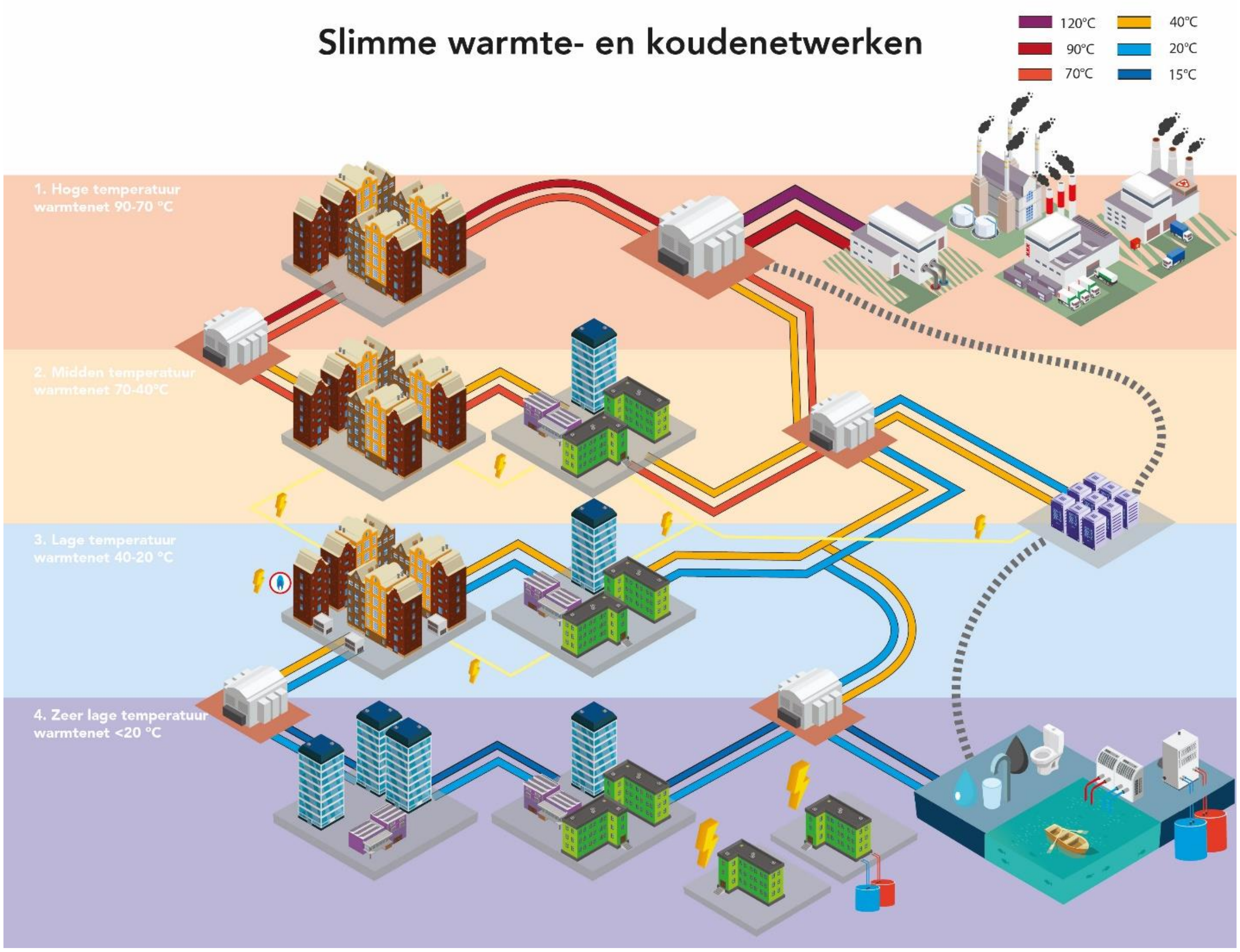
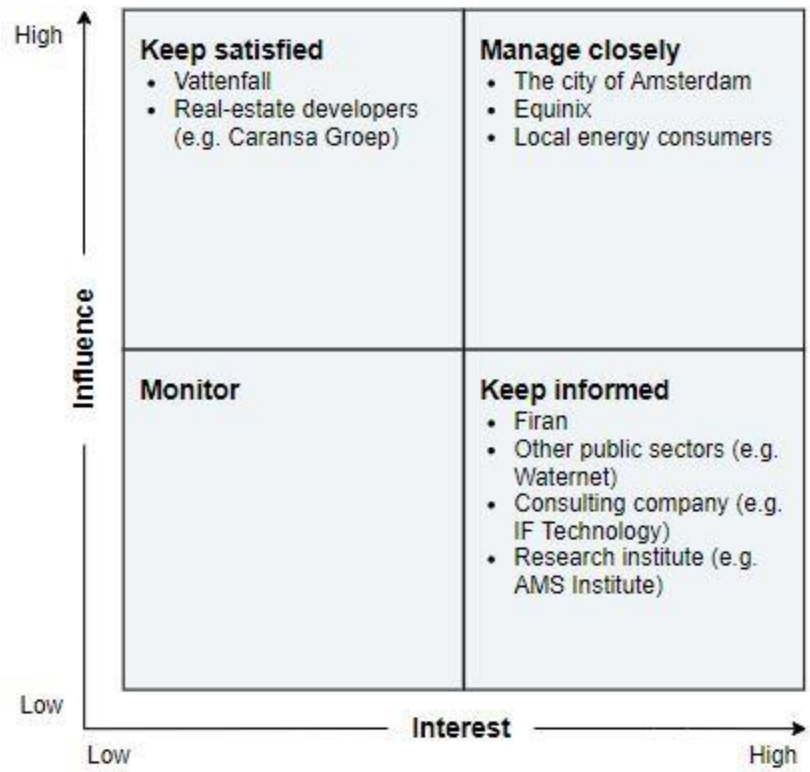


Figure 10b Smart heating and cooling networks in Amstel III

3.2.2. Stakeholder analysis

Multiple parties that have different interests and influences on the sustainable energy development of Amstel III are involved in this case. To understand their roles in district energy transition processes, 'Power Interest Matrix' is employed to systematically category different stakeholders.



The stakeholders that are involved in this case are divided into three categories based on the diagram:

1. High influence - High interest

Actors that are highly interested in the energy transition in Amstel III and at the same time have high impacts on decision-making process shall be fully engaged in this case. Their expectations shall be satisfied. Otherwise, the implementation of the project could be obstructed.

The city of Amsterdam

As a governmental organization, the city of Amsterdam is the major project promoter for the sustainable heating system in Amstel III. This research is mainly from the project-level to analyze the potential future developments. Therefore, the Dutch government, which formulates environmental laws and standards in the social-technical context level and provides institutional constraints to the system, is not included as a stakeholder, but an external constraints provider. The municipality sets the guidelines for other system actors (e.g. regulating roles in the system) to enable cooperation for sustainable network construction. It also has its sustainability index to measure whether an energy solution can be acceptable from many different aspects (e.g. future-proofing).

The city of Amsterdam is enabling the cooperation between Vattenfall and Firan, to integrate data heat system to the existing network of Vattenfall to increase the sustainability in the district heating system. Currently, it is believed by most stakeholders that data centres have no risk in the stability of supply or the reliability of energy-transportation infrastructure since the technical designs of pipes are not complicated. Equinix, which owns all the large data centres in Amstel III, is willing to negotiate the offtake contract to deliver its residual heat in the amount that all parties can agree on for at least 15 years. The cost of the new network will be mostly afforded by ESCOs, for example, the installation cost of heat pumps.

Energy consumers

At the moment, only a few residents are living in Amstel III (Appendix A). In the future, more new residents will come and live in this area, and show different characteristics of the population, which could have different attitudes to current sustainable energy solutions.

The energy price (including a fixed fee) that they will pay for heating and cooling is determined by the Authority for Consumers and Markets (A.C.M.), which sets tariff caps on the supply of heat at various temperatures. The L.T. network is supposed to ease the financial burden of energy users in Amstel III. However, whether the inhabitants can pay less for their energy bills still depends on many other factors, for example, inadequate insulation of houses could lead to more electricity consumption.

Equinix

Equinix is the supplier of the residual heat that is generated from large quantities of servers in data centres. According to the current sustainable energy solution, free L.T. waste heat from data centres (two potential sources: AM5 in the south of Amstel III and AM7 in the north of the area) will be supplied to the heating network, which is the only energy source that Firan is included in its heating plan for the following 15 years. According to the investigation of Firan, it is very optimistic that the available data heat (10% to 20% in the total heat generated by data centres) can cover all the heating demand in Amstel III in the future and no other source is needed. It is expected that datacenters will warm 285,000 new houses in the future. Moreover, the heat generated from data centres is 80% of the consumption of green electricity. So the GHG emissions can also be reduced by switching to the LT solution.

The LT network will supply 28 ℃ LT heat with a two-pipe system. In the future planning, the temperature in the waste heat of data centres should be higher and higher. If the temperature reaches 45 ℃, then the energy demand for household floor heating will be satisfied, and the desired temperature for shower heat and space heat will become easier to reach as well. The temperature can determine the technical designs of the network. For instance, the steel used for pipe material will need to be replaced to fit the future designs of 30 ℃ heating delivery for the next 15 to 30 years.

After the contract expires, it is still possible that Equinix will be forced to move its data centres out of Amstel III, in order to satisfy the new development requirements of the company, such a more stable electricity supply and lower energy price. However, there is still sufficient time for energy system operators, like Firan, to conduct a study to look for alternative sustainable energy sources, for example, the soil energy. This research will only focus on the available energy solutions that can be utilized in this area in the next 15 years.

2. High influence - Low interest

Although some stakeholders can significantly affect the energy transition, they may not have favourable attitudes to the processes and outcomes of the RETs development projects. Some modest incentives shall be created to let them play positive roles in this case.

Vattenfall

At present, Vattenfall is the only supplier in the heating and cooling energy market of Amstel III. It is responsible for the existing HT network that delivers energy to office zones. Many new residential houses and high-rises with higher energy labels will be built in this area in the next 15 to 20 years, which can utilize LT energy through the more sustainable networks that are provided by Firan. In order to meet the new local regulations that ask for stricter sustainable requirements heating network and buildings in the area, Vattenfall has to make tradeoffs and cooperate with Firan to connect LT pipes to the existing district heating network and expand the network to connect more energy consumers in Amstel III. However, Vattenfall has different goals and interests with Firan, which is a government-related NGO. As a profit-oriented company, it desires to receive payback from the investments in sustainable energy networks in 7 years (policymaker 2), while Firan gives the top priority to develop a more sustainable energy system for citizens.

3. Ligh influence - High interest

Those stakeholders have limited impacts on the final decision-making process. However, they provide their expertise and services to help with the details of the energy transition project in Amstel III. Therefore, they should be adequately informed in the discussion concerning the future development of sustainable heating in the area, to ensure that issues, especially those related with public acceptance of energy solutions, will not arise.

Firan

It is not legally possible for Firan to involve in the investment of energy sources, or joining the business as an energy service company (ESCO), which is restricted by Alliander. As a sub-organization of Alliander, Firan has its business demarcation that is regulated by the contract. It focuses on energy transportation and distribution in Amstel III, including the backbone and distribution pipes into the houses, which are also the most costly parts in network construction. In this case, Firan attempts to combine the data heat with heat-cold storage from the geothermal system and supply LT heating energy to more residents.

Third-party organization

Some entities are not part of the local energy system operation or market, while they have a business relationship with other system actors and indirectly influence the developments of a sustainable heating network in Amstel III.

For instance, IF Technology, a consultancy company that positions itself as the leading party in the terminal part of the energy transition, is also a partner of local real-estate developers. The property developers are responsible for the renovation and maintenance of houses in the area. IF Technology helps property developers to find the best conceptual designs for their development on a strategic level. They explore feasible renewable heating and cooling solutions in the area. For example, the development of ATES technology. They try to have a profound understanding of innovative technology as well as the strategic, legal and financial sides of the energy projects, and provide feasible suggestions for real-estate developers. Because of their business relationship with local property developers and expertise in the sustainable energy transition, an expert from IF Technology is also invited as the interviewee to share insights regarding designing a public accepted heating system for Amstel III in this research.

3.2.3. Governance model

In the ideal governance model, the local government and other organisations can form a joint company that connects both energy suppliers and end-users. Local residents can participate and get a share of the energy system, which forms a corporation model and increase the 'Fairness'. However, in the case of Amstel III, since the development in the area is too rapid and not many inhabitants are currently living in this area, it could be hard to facilitate the public participation.

In many sustainable energy development projects, local government's leadership is often critical for facilitating the project implementation. However, for the case of Amstel III, the city of Amsterdam only owns few lands in the area, and only provides guidelines for sustainable heating development. Firan will be responsible for the LT network in the next 15 years. After that Firan goes back to the city of Amsterdam and Waternet, which is a department of the city of Amsterdam, will take over all the infrastructure (e.g. pipes) and maintenance responsibilities. The potential risk of contract lock-in from Vattenfall will still exist in the future system, which threatens to both local inhabitants and the municipality. This lock-in is also the main concerns of many other stakeholders (e.g., Firan) in the system.

In the energy transition case of ArenAPoort, which is another pilot in Amsterdam Southeast, a heating and cooling system is being implemented following the design of an electricity market. At the moment, this means that they are looking to employ one transport company, which will enable cooperation for the infrastructure provider and some ESCOs. This pilot project also provides a reference for the governance model of the district heating system in Amstel III. For instance, different actors can bring their own expertise and resources to develop the project jointly.

4. SCENARIO CONSTRUCTION

4.1. Assessment criteria description

The scenario is composed of various uncertainties and influencing factors of system performance. The relationships among system elements and internal consistency of scenarios shall be checked, and realistic boundary values for system parameters shall be predetermined in order to construct scenarios that can better depict future developments (Bala et al., 2016).

The core aim of this research is to explore the future social acceptance of sustainable heating networks in the context of city transformation in Amsterdam Southeast. Due to the boundaries of the system, as well as time and resources restrictions for this project, a specific case in Amstel III is chosen to focus on. According to the development plans of the local municipality, the primary initiative of city district transformation in Amstel III, which will create livable residential places for around 15,000 new inhabitants, will be accomplished before 2040. At the same time, the city of Amsterdam also would like to be free of natural gas by 2040 (Policymaker 2). Therefore, the year of 2040 is selected to be the time node for scenarios that are constructed in this research.

The future social acceptance in this research is assessed by the fulfilment of a set of societal values and the changes in the importance of these values for local inhabitants over time.

4.1.1. The use of values

Heterogeneous internal elements and diverse stakeholders make the district heating network a complex system that is hard to describe accurately. To evaluate the social acceptance of future sustainable heating solutions from social wellbeing viewpoint, appropriate criteria and indicators shall be chosen to develop the assessment framework. The work of Gallego Carrera & Mack (2010) suggested that indicators, which can link social impacts to energy system-related aspects and logically coherent, are capable of assessing novel energy technologies in respect to some specific system properties, for instance, sustainability. Values, such as privacy and distributive justice, can also act as determinant factors for public acceptance of sustainable technologies with both stimulative and restrictive effects (Milchram et al., 2018). Moreover, some values are highly dependent on each other, which shall be taken into account during the assessment framework building.

The city of Amsterdam is currently using an index to measure the acceptability of sustainable energy solutions in a specific area, which consists of four social values, including Sustainability, Affordability, Openness and Future-proof. In this research, several societal values are selected as main criteria of acceptable heating networks for the public, based on the opinions from experts through interviews and previous experience in research from literature, including sustainability, affordability, openness, and fairness (Table 4). The value ‘Sustainability’, ’Affordability’ and ’Openness’ are selected based on the development goals of Amsterdam municipality for achieving a better and more sustainable future. ‘Future-proof’ is included in the objective (i.e., more accepted system in the future) of the designs that this research hopes to make, and therefore, is omitted in the list. Value ‘Fairness’ is selected based on a literature review from energy consumers perspectives and is added to the list to guarantee the distributive and procedural justice in energy transition processes. This set of values was also discussed with interviewees during the first round interview and survey for verification.

In this research, it is assumed that heating systems, which are environmental-friendly, affordable for local inhabitants, offering sufficient freedom for both energy end-users and suppliers to join or leave, and maintaining justice in its implementation and cost distribution processes, shall be considered as accepted future energy solutions for the public.

Those values provide criteria for the heating network system design, including technological design and decisions on regulation. Although this set of criteria (values) is stable (section 1.1.3), the relative importance of each criterion is in the form of normative claims and can still change over time. This change implies a transformation in the perceptions and preferences of local energy consumers to the priorities of different values under the influence of future trends in some specific social factors (e.g., household income). These dynamic conditions shall also be taken into account. It is because, in some cases, the characteristics of a city district can gradually change in its future developments, such as population (new migrants), economy, physical infrastructure. For instance, a city district with low average household income, low education level, but a large population may probably encounter difficulties in realizing an affordable heating supply system. In contrast, when the population in this city district is with higher average household income, higher education level, and medium population density in the future, it will be relatively easier to fulfil ‘affordability’ in its sustainable heating networks development.

Moreover, designers often face instrumental and conflicting relationships between two or more values (Milchram et al., 2018). Some values even inherently conflict with each other. These conflicts can also lead to changes in the importance of different values, and reveal the potential risks in social acceptance in the future.

Table 4 Values that are selected as assessment criteria

Values	Definition
Environmental sustainability	The system meets its carbon obligation, which is regulated by the law. (55% reduction by 2030 and 95% reduction by 2050)
Affordability	Energy consumers pay costs for the system with a reasonable amount of their budget.

Openness	The system has no lock-in in technology or market for energy suppliers and end-users.
Fairness	The system provides equitable access to energy for local inhabitants and keeps distributive justice and procedural justice in energy transition processes.

For each evaluation criterion, there are a wide diversity of variables in energy system designs that can influence the levels of value fulfilment. By examining the matches and mismatches between the value fulfilment requirements and actual network designs, the public acceptance of sustainable heating systems can be assessed. The scenario analysis in this project helps identify the possible changes in public attitudes in terms of values. The combinations of different value fulfilment levels determine the degrees of the social acceptance of specific sustainable energy solutions in an ordinal way.

4.1.2. Explanation of values

Environmental sustainability

Currently, the municipality of Amsterdam is using carbon footprints as a metric of environmental sustainability. By examining the performance of carbon reduction in different energy solutions based on specific computation rules, the most sustainable systems can be selected (Policymaker 1). The study of Laurent et al. (2012) shows that carbon footprints may not be the best indicator to reflect some particular environmental issues other than climate change. Nevertheless, this research only considers the environmental impact related to GHG emissions and temperature rise, since this is one of the major environmental threats identified in the Paris Agreement and is connected with the EU's goal of carbon-neutral by 2050.

The achievement of carbon reduction of energy, especially heat, can be determined by both technical and institutional designs. For instance, different types of heating networks have different sustainability performance. Low temperature (LT) networks combined with decentralized heat pumps and ATES system is the most sustainable option, which supplies heat at a temperature of approximately 15 ° C. In comparison, high temperature (HT) networks with centralized heat pump, which has higher energy loss, is less sustainable (System operator 2). Not only is the technical design of energy transmission infrastructure crucial for sustainability achievement, but technologies that are used in houses, such as insulation and underfloor heating, are also critical. The loss of energy is relatively high for the old houses that are built in the 1960s in the Amsterdam Southeast (Citizen 1).

Moreover, the regulation also plays a pivotal role in realizing sustainable energy systems. Energy and building regulations determine how the heating network can meet the sustainable requirements by the law. For instance, the new national environmental law, which is coming next year, is expected to change the institutional circumstance for district heating system dramatically (Policymaker 1).

However, not all the stakeholders who are involved in the district heating system are interested in sustainability. For energy end-users in poverty in this area, sustainability is not the biggest issue, and it comes next to the affordability or openness (System operator 2; Citizen 1).

Affordability

Almost all the interviewees recognize ‘Affordability’ as the most critical value in the current heating system. The survey conducted by Morrissey et al. (2020) in grassroots communities from Liverpool also proves that majority of local constituents support that chronic energy poverty and affordability issues shall be given high-priority rating in energy system transitions processes. The importance of affordability is ranked even above environmental impacts and security. The affordability can be vital for some specific groups of inhabitants. There are 6% and 40% of people live in poverty in Amstel III and Amsterdam southeast, respectively (CBS, 2019; Citizen 2). Some local inhabitants often have to turn off the heat in the winter because they cannot ensure that they can afford it (Citizen 1).

Not merely the cost of energy bills should be taken into account, investments in the corresponding infrastructure for novel energy technologies shall be included as well. For the old houses in the area with energy labels from C to G, renovations or reconstruction are necessary to satisfy the technical criteria for connecting with more sustainable energy network (e.g. LT networks), as well as reduce the energy loss. A trade-off has to be made between short-term investments and long-term energy costs. For instance, by increasing the insulation of roofs, walls, and windows of a house, the overall energy consumption can be reduced, which create better affordability for the household. It should be noted that this balance between energy investment and cost is not only for end-users, but also for other parties that are involved in energy systems, for example, housing companies and energy suppliers. A housing company will not choose to do reconstruction with buildings, when it estimates no sufficient payback for the investment (Policymaker2; System operator 1; Citizen 1).

In terms of regulations, there are three kinds of energy tariffs regulated by the law. One of them is a yearly fixed payment for every house. However, at the moment, different types of houses have to pay the same, no matter how large small houses are, or when they are built, which decreases the affordability for some small houses. The municipality is now challenging the heating market to adapt to set tariffs lower than the maximum for smaller houses (Policymaker 1).

Openness

Energy company Vattenfall monopolizes the existing district heating network in Amstel III, which means that energy consumers cannot freely choose energy suppliers and transporters. Morrissey et al. (2020) identified that the ownership of energy infrastructure is considered important in the energy transition by large proportions of energy consumers. Many people believe that energy companies should have less influence in the control of energy generation and distribution, in spite of the fact that, compared to local governments or community leaders, energy companies are still perceived as the most influential stakeholders on household energy practices. Because of the technical and commercial restrictions (e.g. insufficient energy demand) in the energy system, some district heating companies are natural monopolies (System operator 1). This lack of competition creates fewer incentives for energy systems to increase productivity and move toward more sustainable and efficient heat production (Munksgaard et al., 2005). Moreover, this may also cause problems in terms of energy pricing and decrease the affordability for some local inhabitants (Citizen 1).

Studies of Åberg et al. (2020) show that competitions can emerge in two ways. The first is the alternative energy technologies, and the second is the entry of new competitors. At present, several energy sources in the area show potentials as partial substitution of district heating. For example, the residual heat from data centres. In order to enable this open network, some technical and organizational issues shall be thought carefully. First and foremost, other heat suppliers shall be incorporated in a network from a technical point of view. Secondly, there should not be any lock-ins in energy contracts (Policymaker 2).

Fairness

Some interviewees argued that heating network should be a public utility, which provides energy in a non-profitable way like clean water and education, since heating energy is a basic necessity of life that can influence people's health and wellbeing. It should not be a luxury good, and there should be no profit on social boundary conditions. It would be considered fair if everyone in the area can access heating energy in the winter regardless of their circumstances, such as location and income.

Unfairness in energy transition processes may hinder wider acceptance of sustainable technologies and even lead to public protests. Milchram et al. (2018) classified public concerns regarding 'Fairness' into distributive justice and procedural justice. Distributive justice means that the costs and benefits of the network are fairly distributed amongst stakeholders. In energy transition processes, both the responsibility and the cost in realizing more sustainable heating networks should not be transferred to local inhabitants from energy suppliers. Procedural justice refers to involving all relevant stakeholders in decision-making processes and keeping transparent to guarantee fairness. Currently, there are many initiatives in Amstel III that aim to bring all these different stakeholders closer in the context of city transformation. For example, ZO!City, which is an independent platform that regularly organizes information meetings and workshops for local residents in collaboration with the Municipality of Amsterdam and local enterprises.

Other value

There are still some social and moral values not selected to the set of criteria for this project. In this research, through in-depth interviews with experts in different fields, only values highly related to public perception are selected to measure the social acceptance of energy users in Amstel III towards sustainable energy solutions. Other values are either not closely linked with this case or considered as fixed factors. For instance, the reliability of the heating energy source concerning its capacity in supply is not included as criteria. Because the interviewees widely believe that the waste energy from data centres is oversupplied in the heating network in Amstel III.

4.2. Scenario Construction with Cross-Impact Balances Matrix

Cross-Impact Balances (CIB) is a method for the systematic construction of qualitative and semi-quantitative scenarios. It is applied in this research to generate and select the most possible future scenarios and developments based on the internal consistencies among scenario factors. These factors and their interdependencies are identified from the judgements from experts in relevant fields that are collected through interviews and workshop.

Descriptors are defined variables in CIB from the system context used to represent the key attributes of the research system. The combinations of descriptor states and the interactions (mutual promotion or inhibition) among these elements shape the outcomes of the scenario analysis model. Only internally consistent scenarios can be considered as plausible for future development. For instance, a district with a very high ‘average household income’ and low ‘affordability’ for energy services is not realistic. Alternatively, a district with high ‘Annual income per inhabitant’, but has a low ‘education level’ is also unrealistic, since, in most cases, those two elements are positively correlated with each other.

In this research, scenario descriptors are selected through literature review and expert elicitation. In order to describe the social acceptance of sustainable heating networks in future scenarios, the importance of values and critical factors that can have impacts on the importance and fulfilment of values are chosen to be the descriptors in CIB matrix. Eight system determinant factors and their corresponding states have been selected based on the interviews and surveys to experts with different backgrounds involved in the energy grids in Amsterdam Southeast.

4.2.1. Descriptors selection

Importance of values

Although values are factors that are relatively stable over time. The priorities of different values as the criteria of acceptable energy solutions can still be affected by some exogenous factors. Therefore, the level of each criterion (value) in terms of importance is taken into account in this research, since in some specific real-world scenarios, people show little interest in some specific societal aspects in the implementation of sustainable heating. For instance, some local inhabitants may desire a heating system with more stable energy supplies, while the monopolism (value 'Openness') in the network is not their concern. Besides, it should be noted that the importance of each criterion is relative value instead of absolute value. Those weights are computed by comparing the future state of the same criteria with its previous values (Table 4). They represent the preference of public perceptions. Different combinations of criteria importance can lead to different types of scenarios.

Societal factors

Social elements that can represent the characteristics of the local heating system are included in the set of descriptors as well. The combination of those system elements creates many dimensions in the scenario, which increase the number of scenarios exponentially. Therefore, a system elements selection is necessary. Those elements are selected through elicitation search in the interviews with experts that are involved in heating systems in Amsterdam Southeast. There are two types of influencing factors on social acceptance of renewable heating systems: personal factors and contextual factors.

When the number descriptors grow, the workloads for scenario construction and computation will correspondingly increase dramatically, according to the mechanism of CIB matrix. Because of the time constraints of this project, not all the social factors can be included scenario analysis model of this research. Four factors that directly reflect the local conditions related to how energy consumers perceive the values in Section 4.1.1 are selected (Table 5), including household income and public participation as personal factors, and carbon reduction and technical lock-in as contextual factors. The specific outcomes that those factors take in some scenarios, which represent future developments, may reveal values unfulfillment issues that lead to potential risks in the social acceptance of sustainable energy solutions. For instance, it is suggested by experts during the interviews that for the people who live social-houses in Amsterdam Southeast are more sensitive to energy price. 'Affordability' is their priority in deciding whether they will switch to other energy suppliers. This preference indicates that low 'household income' population tend not to accept RETs that could increase their financial burdens on energy bills.

Table 5 Selected personal and contextual factors in the scenario model

Factors	**Description**
Household income	Gross income of all people of a house in Amstel III; Influencing the fulfilment of ‘affordability’
Carbon reduction	The extent that carbon footprint is reduced, compared to the 1990’s level; Indicating the fulfilment of ‘environmental sustainability’
Technical lock-in	The difficulty level to connect to new energy sources
Public participation	The accessibility of the decision-making process for residents

4.2.2. Descriptor states definition

Descriptor states are all the possible future trends of each scenario descriptor. A scenario constructed in this research shall include all the system variables listed in the above sections. Different combination of those variables states represents divergent future developments. Through in-depth interviews with experts and open data collection, the possible states of each scenario variable are identified (Table 6). For instance, the states for descriptor ‘household income’ are defined by referring to the quantitative data from the survey conducted by CBS (2015). The states for values as criteria of social acceptance assessment are determined based on their relative importance with other values, which reflect the changes in energy consumers’ preferences.

Table 6 Summary of descriptors and states for future scenarios

Descriptor	States
Importance of ‘Sustainability’	High: ‘Very important’ Medium: ‘Fairly important’ Low: ‘Not at all important’ or ‘Do not care’
Importance of ‘Affordability’	High: ‘Very important’ Medium: ‘Fairly important’ Low: ‘Not at all important’ or ‘Do not care’
Importance of ‘Openness’	High: ‘Very important’ Medium: ‘Fairly important’ Low: ‘Not at all important’ or ‘Do not care’
Importance of ‘Fairness’	High: ‘Very important’ Medium: ‘Fairly important’ Low: ‘Not at all important’ or ‘Do not care’
Household income	High: More than 20% of households belong to group A, and less than 40% of households belong to group B Medium: Less than 20% of households belong to group A, and less than 40% of households belong to group B

	Income inequality: More than 20% of households belong to group A, and more than 40% of households belong to group B Low: Less than 20% of households belong to group A, and more than 40% of households belong to group B
Carbon reduction	High: 95% reduction Medium: 55% reduction Low: 0 reduction
Technical lock-in	Strong: The main grid that is monopolized by one energy supplier Weak: The network is flexible enough to let the energy consumers choose energy suppliers
Public participation	High: Participate in the planning phase of district heating network development Medium: Not join the discussion, but receive the information on RETs projects Low: Do not care

*Income group:
A. 20% households with the highest disposable income in the Netherlands
B. 40% households with the lowest disposable income in the Netherlands

4.3. Judgments for descriptor relationships identification

In a CIB matrix, one of the core components is the interaction among descriptor states. This interaction is presented in the matrix in the form of semi-quantitative judgements regarding influential links between each pair of descriptor states (e.g. the impact of state x1 of descriptor X on state y1 of descriptor Y) are given based on expert interviews (the second round interview and survey in this research), literature reviews, or other investigations. This quantification of the interdependencies between scenario descriptors is for the purpose of identifying the most plausible futures by computing the internal consistency of each scenario in the later step. The influence could be either 'promoting' or 'restricting' influence based on the specific relationship between factors, and is recorded in the cell of the matrix in an ordinal scale as follows:

-3: strongly restricting influence
-2: moderately restricting influence
-1: weakly restricting influence
0: no influence
+1: weakly promoting influence
+2: moderately promoting influence
+3: strongly promoting influence

Figure 11 Types of direct influences between scenario descriptors

To better explain how the interdependencies between the factors are presented in a CIB matrix, an example is given below to introduce how the judgement is assigned based on influential relationships between descriptor states:

Table 7 Impact of 'Household income' on 'Importance of affordability'

		Importance of 'Affordability'		
		B1. High	B2. Medium	B3. Low
Household income	E1. High	0	0	0
	E2. Medium	1	0	-1
	E3. Low	3	0	-3

In a CIB matrix, the variable in the row represents the descriptor state that has an impact on the descriptor state in the column. In Table 7, it indicates that the level of 'Income' (descriptor states in the row) in an area has a direct impact on "Importance of 'Affordability'" (the descriptor states in the column) for local inhabitants. When the level of 'Income' is 'Low' (E3), it can 'strongly promote' the "Importance of 'Affordability'" to be 'High' (B1), and 'strongly restrict' the "Importance of 'Affordability'" from being 'Low' (B3), and therefore '+3' and '-3' are filled in corresponding cells in the matrix. Nevertheless, when the 'Income' level in the area is 'High' (E1), it does not exert any influence on the "Importance of 'Affordability'", since when most of the inhabitants in this district are with high salaries, they do not need to worry if the heating energy is affordable any more. So '0's are assigned to the cells in the first row.

In this research, judgements in terms of the interdependencies among descriptors were collected through the discussion with the experts and employees in energy-related sectors at the city of Amsterdam and Waternet, during a workshop that was held online. By consulting workshop participants' opinions concerning the trends in the future development of each scenario descriptor under the influences of other factors, the relationships between descriptor states are obtained through the interpretation of their verbatim statements. These relationships based on the qualitative statements of experts are then translated into ordinal data as mentioned above, in order to integrate their insights to CIB matrix and use this algorithmic approach to look for consistent scenarios. This translation from qualitative statements to quantitative cross-impact judgements for CIB matrix is based on the following principles:

1. There are two dimensions for a quantitative judgement in CIB matrix (Figure 11): direction ('+' and '-') and degree (0, 1, 2, 3). The direction represents the type of impact that one descriptor has onto another, which is either promoting or restricting. The degree indicates that to what extend this type of impact exerts its influence. The ‘direction’ can be obtained directly from the statements of workshop participants, while the ‘degree’ requires a more comprehensive understanding of the interdependencies between factors through expert elicitation during the workshop and literature review.
2. The standardization of CIB matrix that enhances the comprehensibility of the data in scenario construction and the outcomes of consistency computation shall be applied. It is based on a principle of compensation (Weimer-Jehle 2006) that requires the sum of each row in a CIB matrix judgement section to be 0. It is because the states of each descriptor are mutually exclusive and exhaustive, which implies the promoting impacts on some specific states are always along with restricting impacts on complementary states of the same descriptor (Schweizer et al., 2012).
3. Extreme values (‘+3’ and ‘-3’) shall be avoided unless strong causal relationships between two scenario descriptors are identified by experts or literature. Therefore, in this research, a limited number of quantitative judgement sets are available for CIB matrix, such as ‘1,1, -2’ and ‘1, 0, -1’ for the rows in the example in Table 7.

An example of the relationship collection and judgement quantification follows, which explains how the verbatim statements from workshop participates and some related literature is interpreted and translated into numerical data in the cells of CIB matrix in this research:

Table 8 Impact of ‘Importance of environmental sustainability’ on ‘Importance of affordability’

		Importance of 'Affordability'		
		High	Medium	Low
Importance of 'Environmental sustainability'	High	-1	-1	2
	Medium	-1	0	1
	Low	0	0	0

Information from the workshop:

1. There is a subtle relationship between the ‘importance of sustainability’ and the ‘importance of affordability’. Some energy users who attach great importance to ‘sustainability’ tend to consider less about ‘affordability’.

Judgements transformation: when local energy end-users value the ‘sustainability’, it has a restricting influence on the ‘importance of affordability’ when the level is high or medium. ‘-1’s are filled into the first two cells in the first row of the matrix to represent these influential relationships, while according to the rule of ‘standardization’, ‘+2’ is assigned to the last cell of the first row for the compensation. No evidence ‘low importance of sustainability’ can also have any kinds of impacts on people who already had many or few concern of ‘affordability’.

2. For some local inhabitants, living in an ‘Environmental sustainability’ environment is a privilege.

Interpretation: this was also discussed in the research of Bardos (2016), in which she suggested that the “importance of sustainability” can be very different to affluent people and low-income households, and ‘sustainability’ should not be only for the benefit of privileged people. In addition, households with lower income are more likely to encounter energy affordability issues in some unexpected circumstances, such as unemployment in COVID-19 situation. They usually spend much more of their household budget on energy costs than more affluent (Lewis, 2020).

3. It should be noted that in the energy transition project of Amstel III, the heating network of renewable energy shall be designed to lower the cost in the future.

Interpretation: otherwise, the expectations of local energy users who bear the cost of network in the initiation phase cannot be met, which may further lead to massive public opposition. The energy price shall be determined reasonably to balance the financial burdens for inhabitants against the investments in CO2 reduction.

It should be noted that only direct influential relationships will be taken into account. For instance, it is likely that a household with higher income has more information/education resources, and therefore has a higher awareness of sustainable development and renewable energy. However, this is recognized as an indirect impact (‘income’ → ‘information/education’ → ‘awareness of renewable energy’) and therefore the cells in the judgement section for scenario descriptors ‘household income’ and ‘importance of environmental sustainability’ are all filled with ‘0’s. In total, 19 non-zero judgement sections that represent the relationships among different scenario factors are identified in the CIB matrix for the case of Amstel III. Appendix D explains how the expert judgements were transformed for other non-zero sections in CIB matrix.

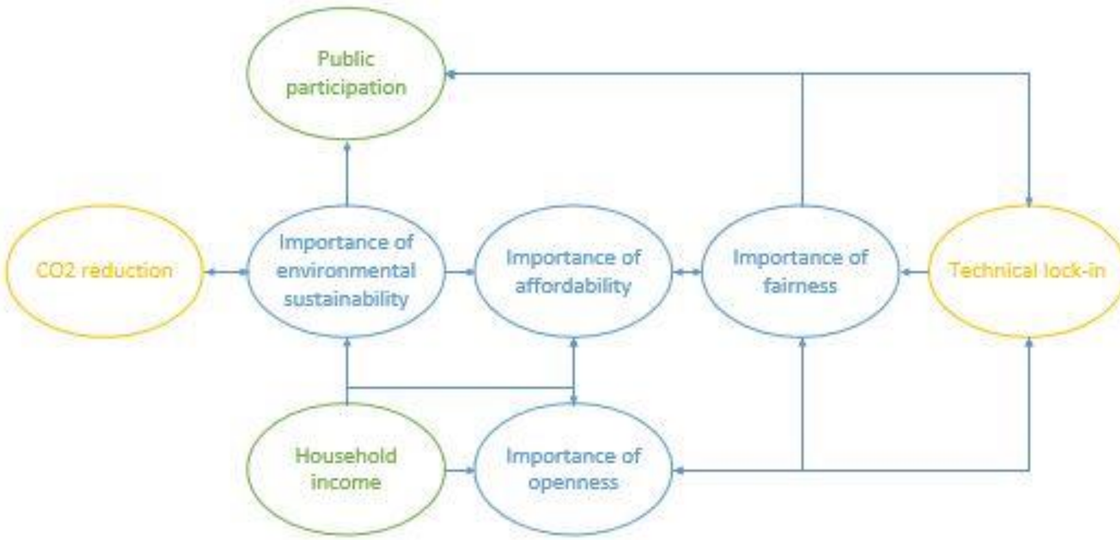


Figure 12 Direct influence diagram for judgments

Those judgement sections that represent the interdependencies of scenario descriptors together form the CIB matrix that is used to identify the consistent scenario through a computation based on the internal consistency of each scenario. The full baseline matrix is shown in Figure 13. 23 variants of 8 scenario factors compose 4374 (=3*3*3*3*3*3*2*3) future developments by selecting 1 of the 2 or 3 variants from each descriptor and combining them to construct a scenario. However, not all those future developments are possible to happen since some of the scenarios could have high internal inconsistency as the example presented in section 4.2. By removing the inconsistent scenarios, the most possible future situations can be identified.

	A			B			C			D			E			F			G		H		
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3	G1	G2	H1	H2	H3
A. Importance of 'Environmental sustainability'																							
A1. High				-1	-1	2	0	0	0	0	0	0	-2	-1	3	0	0	0	0	0	1	1	-2
A2. Medium				-1	0	1	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	1	0	-1
A3. Low				0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	-1	0	1
B. Importance of 'Affordability'																							
B1. High	0	0	0				-1	-1	2	1	1	-2	0	0	0	0	0	0	0	0	1	1	-2
B2. Medium	0	0	0				-1	0	1	1	0	-1	0	0	0	0	0	0	0	0	1	0	1
B3. Low	0	0	0				1	0	-1	0	0	0	0	0	0	0	0	0	0	0	-1	0	1
C. Importance of 'Openness'																							
C1. High	0	0	0	-1	-1	2				1	1	-2	0	0	0	0	0	0	-3	3	1	0	-1
C2. Medium	0	0	0	-1	0	1				1	0	-1	0	0	0	0	0	0	-1	1	0	0	0
C3. Low	0	0	0	1	0	-1				-1	0	1	0	0	0	0	0	0	1	-1	-1	0	1
D. Importance of 'Fairness'																							
D1. High	0	0	0	-1	-1	2	1	1	-2				0	0	0	0	0	0	0	0	2	1	-2
D2. Medium	0	0	0	-1	0	1	1	0	-1				0	0	0	0	0	0	0	0	1	0	-1
D3. Low	0	0	0	1	0	-1	0	0	0				0	0	0	0	0	0	0	0	-2	-1	3
E. CO2 Emissions																							
E1. 0 reduction	2	1	-3	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
E2. 55% reduction	1	0	-1	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
E3. 95% reduction	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
F. Household income																							
F1. Top 20%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0
F2. Medium	0	0	0	1	0	-1	0	0	0	1	0	-1	0	0	0				0	0	0	0	0
F3. Bottom 40%	0	0	0	2	1	-3	1	0	-1	1	1	-2	0	0	0				0	0	0	0	0
G. Technical lock-in																							
G1. Strong	0	0	0	0	0	0	2	1	-3	1	0	-1	0	0	0	0	0	0			0	0	0
G2. Weak	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0
H. Public participation																							
H1. High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1			
H2. Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
H3. Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Figure 13 Full matrix for the case of LT network in Amstel III

5. SCENARIO ANALYSIS

5.1. Evaluation of CIB matrix

In CIB matrix, the internal consistency of each scenario is calculated by synthesizing the impacts that the descriptors have on others and the impacts they receive from others. Those impacts have been transformed into quantitative data, and are summed directly to present all the interdependencies that one scenario element has. It is assumed that the scenario element receives many promoting impacts and only a few inhibiting influences from all the other scenario elements are more likely to appear in future developments. Therefore, in the CIB matrix, the sum of impact values to each scenario element (i.e., the sum of each column) of an internally consistent scenario (a combination of those elements) should be as high as possible. Figure 14 shows one example of consistent scenarios with the highest 'Impact balances' for every selected variant (marked with green in the rows).

Heat networks in Amstel III.scw	A	A	A	B	B	B	C	C	C	D	D	D	E	E	E	F	F	F	G	G	H	H	H
	A	A	A	B	B	B	C	C	C	D	D	D	E	E	E	F	F	F	G	G	H	H	H
A. Importance of 'Environmental sustainability':																							
A1. High				-1	-1	2	0	0	0	0	0	0	-2	-1	3	0	0	0	0	0	1	1	-2
A2. Medium				-1	0	1	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	1	0	-1
A3. Low				0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	-1	0	1
B. Importance of 'Affordability':																							
B1. High	0	0	0				-1	-1	2	1	1	-2	0	0	0	0	0	0	0	0	1	1	-2
B2. Medium	0	0	0				-1	0	1	1	0	-1	0	0	0	0	0	0	0	0	1	0	1
B3. Low	0	0	0				1	0	-1	0	0	0	0	0	0	0	0	0	0	0	-1	0	1
C. Importance of 'Openness':																							
C1. High	0	0	0	-1	-1	2				1	1	-2	0	0	0	0	0	0	-3	3	1	0	-1
C2. Medium	0	0	0	-1	0	1				1	0	-1	0	0	0	0	0	0	-1	1	0	0	0
C3. Low	0	0	0	1	0	-1				-1	0	1	0	0	0	0	0	0	1	-1	-1	0	1
D. Importance of 'Fairness':																							
D1. High	0	0	0	-1	-1	2	1	1	-2				0	0	0	0	0	0	0	0	2	1	-2
D2. Medium	0	0	0	-1	0	1	1	0	-1				0	0	0	0	0	0	0	0	1	0	-1
D3. Low	0	0	0	1	0	-1	0	0	0				0	0	0	0	0	0	0	0	-2	-1	3
E. CO2 Emissions:																							
E1. 0 reduction	2	1	-3	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
E2. 55% reduction	1	0	-1	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
E3. 95% reduction	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0
F. Household income:																							
F1. Top 20%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0
F2. Medium	0	0	0	1	0	-1	0	0	0	1	0	-1	0	0	0				0	0	0	0	0
F3. Bottom 40%	0	0	0	2	1	-3	1	0	-1	1	1	-2	0	0	0				0	0	0	0	0
G. Technical lock-in:																							
G1. Strong	0	0	0	0	0	0	2	1	-3	1	0	-1	0	0	0	0	0	0			0	0	0
G2. Weak	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0
H. Public participation:																							
H1. High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1			
H2. Medium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
H3. Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Impact balances	3	1	-4	-1	-2	3	4	1	-5	6	3	-9	-2	-1	3	0	0	0	-4	4	3	2	-2

Figure 14 'Impact balances' of a consistent scenario

The consistency test of CIB matrix is based on 'Nash equilibrium' (CIB-Lab., n.d.). When switching any selected elements in a scenario would not increase the sum of impact values for every descriptor, this scenario should be considered internally consistent. By checking this internal consistency of each scenario that consists of a combination of descriptors with certain states, all possible future developments can be identified. In this research, 4374 scenarios in total bring a significant amount of computation work. The internal consistency value of each scenario is computed by using ‘ScenarioWizard’, which is a professional software for performing CIB analysis.

The consistent scenarios in the matrix shall be with an ‘Inconsistency Score’ zero. For the case of the energy transition in Amstel III, five consistent scenarios are identified through the computation of CIB matrix. Figure 15 provides an overview of those scenarios as well as their respective descriptor variants:

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th><th>Scenario No. 5</th></tr>
<tr><td colspan="5">A. Importance of 'Environmental sustainability':
A1. High</td></tr>
<tr><td colspan="5">B. Importance of 'Affordability':
B3. Low</td></tr>
<tr><td colspan="5">C. Importance of 'Openness':
C1. High</td></tr>
<tr><td>D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td></tr>
<tr><td colspan="5">E. CO2 Emissions:
E3. 95% reduction</td></tr>
<tr><td colspan="2">F. Household income:
F1. Top 20%</td><td>F. Household income:
F2. Medium</td><td colspan="2">F. Household income:
F3. Bottom 40%</td></tr>
<tr><td colspan="5">G. Technical lock-in:
G2. Weak</td></tr>
<tr><td colspan="5">H. Public participation:
H1. High</td></tr>
</table>

Figure 15 Tableau of all the consistent scenarios

The consistent scenario No.1 (Table 9a) represents the future situation that local inhabitants consider the importance of ‘Affordability’ not very high and value more on ‘Sustainability’ ’Openness’ and ‘Fairness’ for the district heating system. This value change will happen in not only high-income group people, but also the medium or low-income groups who will also actively participate in local sustainable energy initiatives. By then, the CO_2 emission will be reduced dramatically (95% reduction), and the network will be more open (weak lock-in).

Table 9a System elements in consistent scenario No. 1

Consistent Scenario No. 1	
Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High
D. Importance of ‘Fairness’	D1. High
E. Carbon reduction	E3. 95% reduction
F. Household income	F1. Top 20%
G. Technical lock-in	G2. Weak

H. Public participation	H1. High

This phenomenon implies that local inhabitants are willing to pay more for RET due to their increasing environmental awareness. They attach more importance to distributive and procedural justice in the heating system and are pleased to get involved in RET related programs in the neighbourhood. Simultaneously, they cannot tolerate any lock-in in the network with energy suppliers and are willing to scarify more costs to guarantee that the energy network is always open to any suppliers and consumers.

Figure 16 Value changes in consistent scenario 1

Traceability is an advantage of the CIB matrix in scenario analysis, which allows researchers to check which factors are most likely to cause future changes in values. In this research, it is a little counter-intuitive that the consistent scenario indicates that the value 'Fairness' is likely to become less critical for the local energy consumers in the future. To better understand the causes of this outcome, an Impact Diagram is made to display all the impacts on the 'Low' importance of 'Affordability' from other scenario factors (Figure 17). It reveals that the high importance of the other three values contribute equally ('+2' represents moderately promoting influence) to the appearance of this phenomenon. It implies that local people will prefer more sustainable, open heating and cooling network that allows them to participate in the decision-making processes and pay fair shares for the energy services. In order to develop such a system, they are more likely to compromise with the energy cost.

It is noteworthy that the 'importance of affordability' is a relative value. This outcome does not indicate that the value 'Affordability' is not essential any more. Nevertheless, compared with other values, local energy consumers tend to give up some of ‘affordability’ in exchange for more ‘environmental-friendly’, ’open’ and ‘fair’ district heating networks.

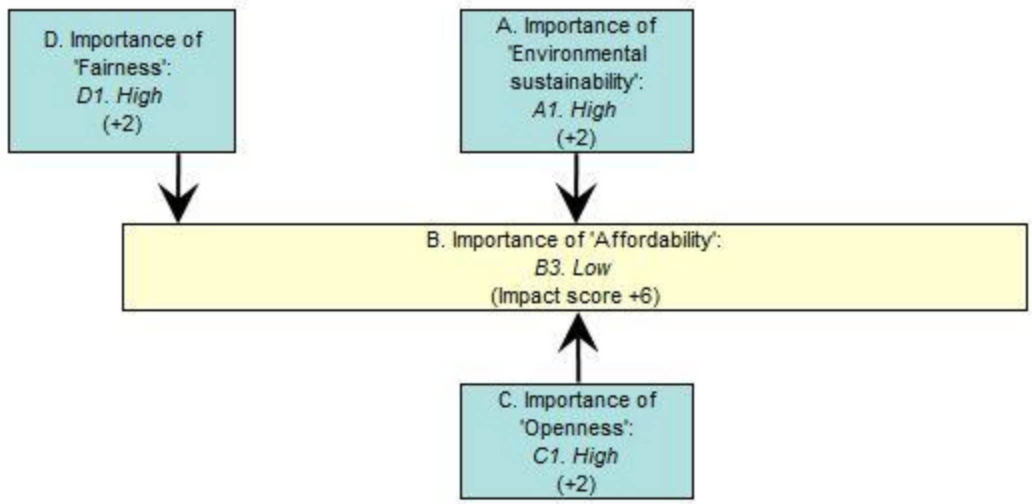


Figure 17 Impact diagram of descriptor variant ‘Low importance of affordability’

The consistent scenario No.2 (Table 9b) is mostly the same as the first one, while the importance of ‘Fairness’ is expected to remain at the same level in the future. In this scenario, there is a tradeoff between the importance of ‘Affordability’ and the importance of ‘Sustainability’ and ‘Openness’. It implies that people with high income (top 20% group) will be more likely to care about the emission reduction of sustainable energy solution, as well as the lock-ins the district heating system in the future.

Table 9b System elements in consistent scenario No. 2

Consistent Scenario No. 2	
Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High
D. Importance of ‘Fairness’	D1. Medium
E. Carbon reduction	E3. 95% reduction
F. Household income	F1. Top 20%
G. Technical lock-in	G2. Weak
H. Public participation	H1. High

The only difference between the consistent scenario No.3 (Table 9c) and the first one (Table 9a) is the ‘Household income’ level. This scenario indicates that households with medium level income are also willing to give up the importance of ‘Affordability’ for higher importance of other values. Like the high-income group, they cannot tolerate any lock-ins in the district heating network and will be more strict with the CO2 reduction capability of sustainable solutions. They are more willing to participate in local sustainable energy projects' decision-making processes to ensure procedural and distributive justice.

Table 9c System elements in consistent scenario No. 3

Consistent Scenario No. 3	
Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High
D. Importance of ‘Fairness’	D1. High
E. Carbon reduction	E3. 95% reduction
F. Household income	F1. Medium
G. Technical lock-in	G2. Weak
H. Public participation	H1. High

The consistent scenario No.4 (Table 9d) and No.5 (Table 9e) both reflect the preferences of people with lower income. They are still very close to the scenarios for high or medium-level income households. This implies that, for no matter which income groups in this area, the importance of ‘Affordability’ is not their first concern on sustainable heating energy options selection, while sometimes the value ‘Fairness’ is also not prioritized compared with ‘Sustainability’ and ‘Openness’.

Table 9d System elements in consistent scenario No. 4

Consistent Scenario No. 4	
Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High
D. Importance of ‘Fairness’	D1. High
E. Carbon reduction	E3. 95% reduction
F. Household income	F1. Bottom 40%
G. Technical lock-in	G2. Weak
H. Public participation	H1. High

Table 9e System elements in consistent scenario No. 5

Consistent Scenario No. 5	
Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High
D. Importance of ‘Fairness’	D1. Medium
E. Carbon reduction	E3. 95% reduction

F. Household income	F1. Bottom 40%
G. Technical lock-in	G2. Weak
H. Public participation	H1. High

5.2. Other possibilities

The inconsistency scores that are obtained by evaluating the scenarios through CIB matrix. The results highly depend on the subjective judgements concerning the interdependencies of scenario factors collected during the workshop (Section 4.3). In case some of the relationships are not identified by the participants, the sensitivity analysis is conducted to validate the robustness of outcomes (consistent scenarios). The difference in results with the baseline matrix will be tested through the sensitivity analyses.

According to Schweizer et al. (2012), there are two major approaches to perform sensitivity analysis in a CIB matrix: a. adding new cross-impact relationships to the scenario descriptors in matrix based on assumptions, and b. making adjustments to the impact values in the cells in non-zero sections. The combination of these two approaches can also be one option, while it is too complicated to make the assumptions for this type of situations, and therefore is not suitable for this project due to the research scope.

5 sensitivities are investigated in this project. 3 of them are type ‘a’, and 2 of them are type ‘b’. One of those sensitivities is presented:

Impact of the importance of 'Sustainability' on the importance of 'Openness':

The baseline matrix assumes that there is no direct influence between the ‘importance of sustainability’ (IS) and the ‘importance of openness’ (IO). Therefore the corresponding section is filled with ‘0’s.

Table 10 The corresponding section in the baseline matrix

		Importance of ‘Openness’		
		High	Medium	Low
Importance of 'Sustainability'	High	0	0	0
	Medium	0	0	0
	Low	0	0	0

In this sensitivity analysis, a new assumption is made for the impacts from IS on IO: The negotiation among different stakeholders may hamper the progress in RETs deployment. Local energy consumers who consider ‘environmental sustainability’ as highly important value do not desire any possible delays in the sustainable heating network development, and tend to let Vattenfall do its job for more efficiency.

The modification to the baseline CIB matrix and corresponding results are presented below:

Table 11 The section in the sensitivity analysis matrix No. 1

<table>
<tr><td colspan="2"></td><td colspan="3">Importance of ‘Openness’</td></tr>
<tr><td colspan="2"></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Importance of 'Sustainability'</td><td>High</td><td>-1</td><td>0</td><td>1</td></tr>
<tr><td>Medium</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Low</td><td>0</td><td>0</td><td>0</td></tr>
</table>

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th><th>Scenario No. 5</th><th>Scenario No. 6</th><th>Scenario No. 7</th><th>Scenario No. 8</th><th>Scenario No. 9</th><th>Scenario No. 10</th><th>Scenario No. 11</th></tr>
<tr><td colspan="11">A. Importance of 'Environmental sustainability':
A1. High</td></tr>
<tr><td colspan="7">B. Importance of 'Affordability':
B3. Low</td><td>B. Importance of 'Affordability':
B1. High</td><td colspan="2">B. Importance of 'Affordability':
B3. Low</td><td>B. Importance of 'Affordability':
B1. High</td></tr>
<tr><td>C. Importance of 'Openness':
C1. High</td><td>C. Importance of 'Openness':
C2. Medium</td><td colspan="2">C. Importance of 'Openness':
C1. High</td><td>C. Importance of 'Openness':
C2. Medium</td><td colspan="2">C. Importance of 'Openness':
C1. High</td><td>C. Importance of 'Openness':
C3. Low</td><td colspan="2">C. Importance of 'Openness':
C2. Medium</td><td>C. Importance of 'Openness':
C3. Low</td></tr>
<tr><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td><td colspan="3">D. Importance of 'Fairness':
D1. High</td><td colspan="2">D. Importance of 'Fairness':
D2. Medium</td><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td></tr>
<tr><td colspan="11">E. CO2 Emissions:
E3. 95% reduction</td></tr>
<tr><td colspan="3">F. Household income:
F1. Top 20%</td><td colspan="2">F. Household income:
F2. Medium</td><td colspan="3">F. Household income:
F3. Bottom 40%</td><td>F. Household income:
F1. Top 20%</td><td>F. Household income:
F2. Medium</td><td>F. Household income:
F3. Bottom 40%</td></tr>
<tr><td colspan="11">G. Technical lock-in:
G2. Weak</td></tr>
<tr><td colspan="8">H. Public participation:
H1. High</td><td colspan="3">H. Public participation:
H2. Medium</td></tr>
</table>

Figure 18 All the consistent scenarios for the sensitivity analysis matrix No. 1

Most consistent scenarios still show high or at least medium level of IO, while there are still two scenarios (No. 8 and No. 11) indicate the lower IO in the future. Another noteworthy outcome is that in those two scenarios, the importance of ‘Affordability’ (IA) is estimated to be higher, which is significantly different from the baseline matrix. It is because the mutual restricting influences between IA and IO lead to the opposite directions in their changes.

However, 9 of 11 consistent scenarios obtained from this sensitivity analysis matrix show the features as presented in Table 12, which are very close to the baseline matrix results. This outcome indicates that in general, the internal consistencies of most scenarios from the baseline matrix are not very sensitive to this adjustment. Those consistent scenarios are still likely to be future developments.

Table 12 Some consistent scenarios in sensitivity analysis matrix No. 1

Descriptors	**Descriptor states**
A. Importance of ‘Environmental sustainability’	A1. High
B. Importance of ‘Affordability’	B3. Low
C. Importance of ‘Openness’	C1. High or C2. Medium

D. Importance of 'Fairness'	D1. High or D2. Medium

The rest sensitivity analyses can be found in Appendix E. Overall, the results from most of those sensitivity analyses do not show much deviation from the baseline matrix in section 4.3 in terms of the set of consistent scenarios. Only when adding a restricting influence of 'importance of fairness' on 'CO2 emission', the consistency of some scenarios was strongly affected, which implies those scenarios are sensitive to this change.

6. POTENTIAL SOCIAL ACCEPTANCE ISSUES DISCUSSION

In this chapter, the current district energy systems in Amstel III are examined in terms of their capabilities in dealing with future value changes. Potential issues concerning the lack of social acceptance are revealed, and recommendations are proposed accordingly.

6.1. Current energy solutions in Amstel III

The district heating and cooling network designs shall match the possible future developments concerning the value changes obtained through CIB matrix analysis in the previous section (Table 13). Otherwise, issues concerning social acceptance could occur and hinder the development of RETs in this area. As introduced in section 3.2, there are currently two types of energy networks in the future planning of sustainable heating and cooling network expansion in Amstel III.

Table 13 Consistent scenarios in the baseline model

Descriptors	Descriptor states in consistent scenarios
Importance of 'Environmental sustainability'	High
Importance of 'Affordability'	Low
Importance of 'Openness'	High
Importance of 'Fairness'	High or Medium
Carbon reduction	95% reduction
Household income	All groups
Technical lock-in	Weak
Public participation	High

The existing network

Although local inhabitants may not oppose the increasing energy price of the existing network, the utilization of heat energy that is mostly generated by combustion can hardly satisfy the CO2 reduction requirements. Alternative energy sources shall be integrated into the network. However, at the moment, the research and investigation of geothermal resources in Amstel III are not sufficient. Other feasible RETs (e.g., solar thermal system) shall be deployed to the area before the geothermal energy solution in the long-term planning gets mature. Either way, the existing main heating grid will have to be replaced with a more sustainable system in order to meet the environmental sustainability goals.

Furthermore, the natural monopoly of Vattenfall can still cause several issues that harm the social acceptance of this existing grid. Firstly, it hampers the entering of other energy suppliers, and cannot meet the public expectation of a highly 'open' system. Besides, this monopoly and non-transparency in planning will lead to distrust of the public on energy supplier, which can hurt the willingness of inhabitants to take part in local RET development projects (Kalkbrenner & Roosen, 2016). There is still a lack of system design to increase public participation in the decision-making, albeit the government's effort in the environmental promotion in the neighbourhood of Amsterdam Southeast to raise awareness and understanding of RETs. Also, distributive justice in the existing system will be hard to ensure without the intervention of the municipality. For instance, the case of ‘tariff on small houses’ in section 4.1.2 is still possible to happen in the future.

It is estimated that a broad diversity of people will live in Amstel III in the future, from students and first-time house buyers to business-owners (Gemeente Amsterdam, n.d.). The ‘affordability’ is not considered highly important for citizens with lower household income in the forecast based on the scenario analysis, while this phenomenon can be interpreted differently in the case of Amstel III: local inhabitants choose to suffer in silence. According to the interview with Citizen 1, there are still some inhabitants in social houses who choose to shut down the indoor space heating system for the whole winter in Amsterdam Southeast because high energy costs are unaffordable for them. Even though they do not oppose the existing system openly, energy is a basic necessity of life and should not be profitable in harming people’s health. It is hard to guarantee the affordability for the local inhabitants since the monopoly of Vattenfall provides little room to the negotiation concerning the pricing for the lower-income group. If this situation cannot be improved in the future, the solution should not be accepted for the public.

LT solution

This sustainable energy solution utilizes residual heat from data centres, which is more environmental-friendly and open for different LT energy sources, could be considered acceptable for energy users in Amstel III in terms of sustainability. Currently, LT networks are all small scales and need to be integrated into the main grid in the future. It is because the data heat is hard to reuse without an extensive network (Judge, 2020).

In the ideal scenario, local inhabitants will be able to choose their energy suppliers every year to satisfy their requirements for the value of ‘Openness’. However, flexibility highly depends on the maturity of network development. Due to the technology limitations, the district heating network cannot be as flexible as the electricity grid that allows more suppliers to join in the short term. The technology lock-ins will still exist. Moreover, since Firan can only act as an infrastructure operator in the network and cannot participate in the business directly (Alliander charges only a grid fee). Vattenfall will remain the monopoly heating energy supplier in Amstel III in the foreseeable future, which means the LT system still needs to be improved to meet the increasing public expectations for ‘Openness’.

Booster heat pump for the individual dwelling is an indispensable part of the LT solution in Amstel III. It boosts the temperature for domestic hot water when LT energy is not sufficient to satisfy the demand. Compared with the traditional boiler, it has distinct advantages in CO2 reduction and energy efficiency, while the investments could be higher (Vourvoulias, 2020). However, in the case of Amstel III, ‘Affordability’ is regarded as a less critical factor for energy consumers. Therefore the heat pump option is likely to be accepted by the public, albeit the high initial costs. Besides, the energy costs with booster heat pumps will be lower than boilers in the long run.

In addition, the participation of Firan in LT network construction and operation can act as a counterweight to Vattenfall’s monopoly on energy supply in Amstel III. As a nonprofit NGO, Firan can obtain a higher degree of public trust than commercial organizations, which makes it a valid proxy for local energy consumers (Yu, 2013), and increase the procedural justice in planning and decision-making processes of RETs.

6.2. Results verification

Outcomes of the last section indicate that the LT network solution will be the more acceptable option for local inhabitants in Amstel III. However, the results are based on the conceptualized model, which needs to be further verified whether they are in accordance with the real-world developments. Through the interviews with experts that directly participate in the sustainable energy development projects in Amsterdam Southeast (Section 2.2.3), the potential risks and drawbacks for LT network to fail in fulfilling the values that are expected to be more important for local energy consumers in the future (Section 5.1) are identified. Table 14 presents a summary of findings from these interviews.

Table 14 Interview summary

Organization	Statements
Firan	- Vattenfall will still be responsible for the whole chain of energy supply in Amstel III. Therefore the system may remain the lock-in, since Vattenfall can provide contracts to all new property developers and house owners to this area for the next 15 years. This will be too risky to protect the interests of local inhabitants.
Vattenfall	- The adaptation to LT system may lead to path dependency in the technical standard of the network. There is a potential risk that there is no expected return for this investment. Which temperature shall be used for the new network is still debatable. - The efficiency in negotiation among different parties in sustainable heating network development should be improved.
IF Technology	- There is no sufficient consideration of the cooling capacity that the new system can provide. The potential commercial value of cooling is much higher than heating according to the energy demand in Amstel III. - In order to meet the new legislation that will come into effect in 2021, ATES system has to be used to ensure a cost-efficient and

	affordable energy delivery system. The master plan for using the soil energy and storage system is needed. - The scale-down approach that the city of Amsterdam is using in planning may not be able to consider different energy demands from every entity that connects to the network. - The quality of equipment at two ends (suppliers and consumers) of the heating and cooling network can also cause disturbance of the energy delivery, which is responsible by the ESCOs. - It could be less cost-efficient to have a more open system because of natural monopoly. The cost of infrastructure construction is the most substantial part of the total investment for sustainable energy development.
The city of Amsterdam	- The failure of houses' insulation system can lead to more electricity consumption for space heating and increase the energy cost for local consumers. - Currently, information and knowledge for the underground situation in Amstel III are not sufficient, and the possibilities to utilize soil energy system need to be further clarified.
Citizens	- The innovation of technology will decrease the machine (e.g. computer chip) temperature within data centres, which may cause a shortage of heating energy supply. Therefore data heat may not be a reliable energy source in the future. - Moreover, every change to the existing system will require new investment. This additional cost could be transferred to local energy consumer and increase the financial burden of citizens.

In general, there are still numerous problems in the current LT network concerning the value fulfilment. Further improvements to the system designs are necessary to meet the requirements of the energy consumers.

It is worth noting that some social acceptance issues are still not captured by the scenario analysis model. For instance, the knowledge with respect to the underground conditions in Amstel III can be critical for assessing the acceptance of energy solutions. The amount of heating and cooling energy stored in the soil depends on the available subsurface space. According to the research of Afanasyev (2020), the energy transportation project in Amstel III requires more than 5,000 m of pipes, which means there is a minimum 10,000 to 20,000 m2 of subsoil space required for the heating and cooling network. Finding and reserving sufficient space for the pipes has become one of the bottlenecks of sustainable energy development in the area, which cannot be overlooked.

This absence of factor ‘knowledge’ is due to the initial assumptions and constraints in the assessment framework building for social acceptance. Only the public attitude related to values from local energy consumers is considered the major criterion in this project. Other factors, such as knowledge and practice, are either not from end-users' perspective or considered as only have indirect impacts on social acceptance in this research.

In addition, through the interviews, the conflicting interests and concerns of different stakeholders can be observed directly. For instance, Firan suggested that the monopoly of Vattenfall is the biggest issue in designing a public accepted network, while Vattenfall believed that it would be more efficient for them to work on the RET project alone without the disruptions from other parties. The stakeholder engagement could be crucial for the implementation of public accepted energy solutions. Otherwise, no party can eventually benefit from endless arguments. The advantage of CIB matrix in dealing with the disputation among different stakeholders will be introduced in Chapter 8.

7. CONCLUSION AND DISCUSSION

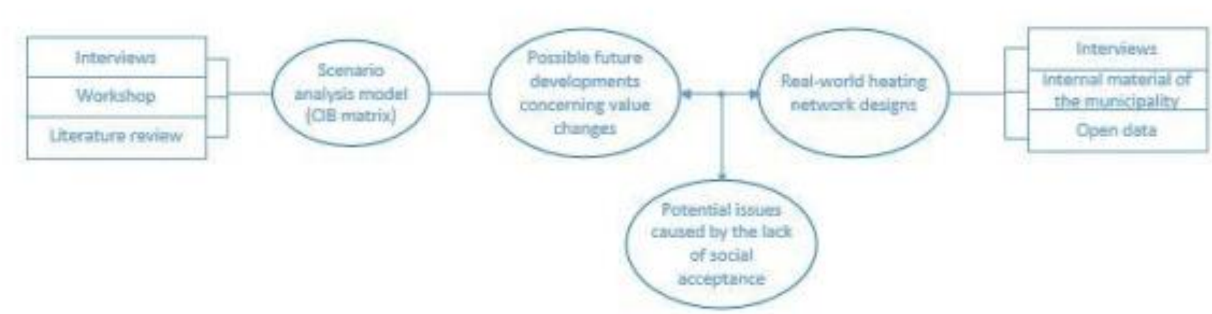
This chapter provides the conclusions of this research. The answer to each sub research questions is provided to address the main research problem. Also, the social and scientific relevance of this project is explained.

7.1. Summary of the research

This research's main question is *'How can the future social acceptance of sustainable heating systems be assessed and improved for a city district's long-term development plan in Amstel III?'*

To assess the future acceptance of local inhabitants in Amstel III, this project anticipated future developments in this area through a scenario analysis approach, which assisted in identifying potential risks in the lack of positive public attitude to sustainable heating solutions. This forecast of possible futures helped the long-term planning of district heating and cooling development project because it enhanced the understanding of public preference of different energy options, which is one of the keys to mitigating the future's potential challenges.

In this project, a case study is conducted to unveil the possible social acceptance issues in the future sustainable heating and cooling network development in Amstel III, based on scenario analysis and semi-structured interviews. By comparing the anticipation of plausible futures and the district heating network designs in Amstel III, the mismatches that show the potential risks in the lack of social acceptance can be identified. CIB matrix, a scenario planning method with qualitative and quantitative attributes, was employed to forecast the future district heating system's possible futures concerning the value changes.



The outcomes of the CIB matrix indicate that the local community in Amstel III will tend to attach more importance to environmental sustainability, openness, and fairness in the sustainable energy transition. The LT district heating solution is more likely to be accepted by the public for its better performance in reducing CO_2 emissions and improving energy efficiency. Besides, the

LT network provides possibilities in connecting more renewable energy sources, and promotes procedural justice by involving non-commercial parties in the planning and decision-making processes.

However, there are still many drawbacks in current LT network designs that could hinder the implementation. For instance, the issue of path dependence in the technical standard. The networks shall employ robust design approaches to minimize the impacts of the exogenous factors. For example, the technology innovation may decrease the working machine temperature and reduce residual heating energy availability from in data centre to the network in Amstel III. By designing the more open network that integrates sources that supply energy stably in the long-term plan, the impacts from altering energy sources can be mitigated

Furthermore, it is essential to have alternative energy sources for the LT network in Amstel III besides the residual heat from data centres. This will not only secure the heating supply in the future before the technology for utilizing soil energy is mature, but also increase the trust of citizens concerning the reliability of the sustainable heating system. The government could provide financial incentives (e.g. subsidise) to boost the development of different RETs in a balanced manner, since there could be more than one accepted sustainable energy solutions for the public.

Different actors in the system may have conflicting interests, such as Vattenfall and Firan. The legislation (e.g. building laws) shall create the institutional environment that shapes the space of choices and enable communication and collaboration among different stakeholders to realize the sustainable development goals.

In addition, the results of the scenario analysis show that local people tend to have a lower carbon-footprint living environment in the future. Besides, they are sensitive to the lock-ins and distributive and procedural justice issues of the system. Therefore, the sustainable network shall be ensured that it is open to any energy sources and try to involve local consumers to the decision-making processes in the best possible way.

7.2. Answers to research questions

Four sub-questions are formulated to reduce the complexities in the research problem:

1. **What are the key system elements in district heating networks that can influence the fulfilment of public acceptance assessment criteria?**

In this research, values are used as the criteria to assess the social acceptance of RETs, because they are enduring beliefs that people have and particularly suitable for long-term planning.

Two types of impacts that can lead to the value changes are identified through the interviews with experts and literature review. First, the interdependencies between values can have either promoting or restricting influences on the importance of different values. Tradeoffs will have to be made when the value conflicts cause the dilemma in sustainable energy solution designs. Second, some personal and contextual factors that can reflect or affect the value fulfillments in the case of Amstel III are also considered as key elements in realizing socially accepted energy designs.

2. How to specify key system factors in scenario analysis models?

Four values (including sustainability, affordability, openness, and fairness) and four social factors (including household income, public participation, CO_2 reduction, and technical lock-in) are used to construct the scenarios in this research. These critical system elements concerning social acceptance and their interdependencies are identified through semi-structured interviews and a collaborative workshop with experts. The specification of those factors is obtained by transforming experts judgment into quantitative data in a Cross-Impact Balances matrix (CIB) matrix.

3. What are the most plausible future scenarios for the social acceptance of sustainable heating solutions?

The forecast of plausible futures is performed by examing the internal consistency of each scenario that is constructed through the evaluation of CIB matrix. Highly internally consistent scenarios are considered as the most possible future developments in the heating system of Amstel III. In the end, 5 of the total 4374 scenarios, which have Inconsistency Score 0, pass the CIB matrix assessment. They describe the future that local inhabitants will have increasing concerns on the importance of sustainability, openness and fairness in RETs network developments, while the 'affordability' will be less critical for whichever household income groups in this area.

4. What are preferable designs for a district heating and cooling network?

Through the forecast using the scenario analysis, the public requirements for the sustainable heating network are identified. The designs shall meet their expectations concerning the changes in values. Otherwise, social acceptance issues could occur in the whole life span of an energy project.

By comparing the energy solutions in the 'Heat Plan' of the city of Amsterdam, the LT heating network that reuses the waste energy from data centres can be the more accepted option for the public because of its advantages in satisfying the CO_2 reduction objective and reduce operation monopoly. However, there are still many drawbacks in the current LT designs in meeting requirements of public acceptance in the future scenarios, which needs to be further improved.

7.3. Social and scientific relevance

This research presents a novel approach for investigating the social acceptance of the sustainable energy transition. The considerations from technical designs, institutional environment, and commercial feasibility of the renewable energy network are also integrated with the scenario analysis models. The research outcomes provide more detailed semi-quantitative assessments of renewable energy network alternative to the existing heating system in Amstel III, as well as recommendations regarding sustainable network development planning that can better convince local end-users.

Besides, this research will closely match with the goals of CoSEM study. On the one hand, it will have a straightforward design for a multidisciplinary system: sustainable energy delivery system, which is relevant to research fields, including energy engineering, infrastructure management, policy management. On the other hand, CoSEM analysis methods and thoughts will be applied to analyze the problems systematically and generate design solutions.

8. REFLECTION

8.1. Limitations of the research

Connections with the case of Amstel III

This project investigates the sustainable heating and cooling solutions in Amstel III, including actors analysis, available technical designs, and feasibility analysis for different governance modes through in-depth interviews and surveys with project-related experts. However, the conceptualization of the case may still not be able to represent all the characteristics of the research system, which is restricted by the computation capacity. It is because only a few dimensions are considered in the conceptualized model of this project. Besides, the information that is gathered from interviews is mostly subjective. Only a few interviewees were available to participate in this project, resulting from the limited number of social connections.

The validity of the research approach

The judgement collection is based on personal experience and knowledge of participants, which are rather subjective. Therefore, some biases may exist in the scenario analysis model. Also, the semi-quantitative data were standardized before filling into the matrix. However, the standardized number may not represent the influential relationships between scenario descriptors exactly.

Sensitivity analysis is conducted in Section 5.2. Although the results of most sensitivities are not significantly different from the baseline model, it reveals that some different opinions (e.g., adding a restricting influence of 'importance of fairness' on 'CO2 emission) could lead to different results.

Verification of the scenario analysis model

There are still some potential risks for implementing the sustainable heating system in Amstel III that cannot be evaluated with the research approaches in this project, such as:

1. The comparison of 'Scale-up' and 'Scale-down' approaches in sustainable energy development planning;
2. The technical designs for the utilization of soil energy;
3. The organizational designs for the district heating system stakeholders (e.g. the joint company that involve all actors).

It is because that the limitation in the time and other resources for this project makes the initial assumption can only consider a limited number of assessments concerning the social acceptance issues. Further research could involve more dimensions (e.g., 'knowledge' or 'practice' besides 'public attitude' that is assessed with values) to investigate pubic acceptance in the RETs.

8.2. Limitations of CIB matrix

The scenario analysis should be a useful tool to explore different possibilities in future trends. It helps the decision-makers prepare for future challenges and mitigate the potential risks in strategic planning.

However, the scenario analysis outcomes in this project only provided 5 quite similar plausible future development through the forecast of CIB matrix. These unusual outcomes result from the insufficient input information in the scenario construction. Among the 56 (8*8-8) sections in the CIB matrix (Figure 19), only 19 are filled with numbers representing more critical influential relationships between system factors. Some impacts that are harder to identify could have been missed and led to less divergent outcomes in future development anticipation.

Also, due to the assumption for the semi-quantitative judgment assignment in 4.3, simple logical structure sometimes may not sufficiently reflect the complex interdependencies between scenario factors. For instance, in this research, the levels for the importance of values are defined with 3 scales ('high', 'medium' and 'low') based on the comparison with currently states, while in the real world people may have more subtle perception with the importance of values and their interdependencies with other values.

The quality and completeness of the CIB matrix building in this project are restricted by the time and resource. One of the most significant limitations of the CIB matrix application is the available time that each expert has to participate in the scenario construction. There are 8 descriptors in the CIB matrix used for this research, which means large sets of judgements concerning the relationships between scenario descriptors shall be provided. In this case, 56 judgement sections with more than 500 cells require around 2.5 hours (assuming each cell needs 20 seconds to provide judgement) for each participant to finish, which is not possible considering the availability of experts. Moreover, the participants need more time to provide judgments, because they normally do not have time to prepare before the interviews or workshops for the discussed topics that the CIB matrix is built for, and they are not trained to use this novel method before. Therefore, in this research, we only collected verbatim statements concerning the interdependencies of critical factors and then translated their qualitative judgement into ordinal data for CIB matrix cells by ourselves.

8.3. Future research

CIB matrix, which allows experts' participation, enhances the clarity and transparency in the scenario construction process (Broll et al., 2020). Through the practice in this project, the CIB matrix was found to be a great tool in supporting the decision-making in regional level RETs development planning, particularly for the long-term plan.

Due to the limitations in this research, the full potentials of CIB matrix was not reached. Future research could try to obtain more resources to build more complete models to improve the quality of the result and integrate this method with other research methods to achieve more research objectives.

Application of CIB matrix

One of the most significant issues that are widely recognized by the interviewees is the difficulty in negotiation. There are multiple stakeholders involved in the districting heating system in the case of Amstel III (Section 3.2.2). Each of them has its own interest and concerns in the RETs development processes, which can sometimes conflict with others. For instance, Vattenfall believes that communications with other parties slow down the progress in RETs deployment, and it will be efficient to develop an energy network that can be public acceptable by itself. On the contrary, Firan proposes the monopolization of Vattenfall is the cause for the strong lock-in in the district heating system of Amstel III, which may harm the social acceptance of the network. Besides, there are also some other issues concerning the negotiation. For instance, it is reflected by some of the interviewees that the time is hard to coordinate for the meetings that involve more stakeholders.

Strong organization and top-down leadership could be necessary, since many efforts are required from participates in accomplishing this kind of task. Besides, the traceability and transparency of the CIB matrix allow the participants to trace the causes of specific results and help them to understand the requirements and concerns of each other, as well as all the complexities in systems. Their trust in the outcomes of the projects can also be improved in this process.

Therefore, strong organizations with coordination capacity are recommended to employ CIB matrix to mitigate the conflicts in the negotiation through participatory modelling. In the case of Amstel III, a joint company that involve more stakeholders could be formed in that area to work on sustainable energy development together. Experts or representatives from different parties can collaborate in one department and employ this participatory modelling method to reach a consensus.

The combination with agent-based modelling

Scenario analysis approach can help to forecast the plausible future developments in a specific area with high uncertainties. In this research, the scenario technique, especially Cross-Impact Balances method, is employed to anticipate the social acceptance of sustainable energy solutions in Amstel III. The CIB model can provide an understanding of influential relationships between different system elements and identify the tradeoffs local people are most likely to make for the conflicting values. The results from CIB model provide more information regarding the characteristics of the city district developments and population, to the construction of the agent-based model (ABM) that can further analyze the behaviours of local residents and predict their acceptability of renewable energy with more insights.

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APPENDIX A. SCENTIFIC PAPER

A separate document.

APPENDIX B. CHARACTERISTICS OF AMSTEL III

Population (CBS, 2019)

Table 15

Characteristics	Data
Total number of inhabitants	710
Gender	Male: 390 Female: 320
Age groups	0 to 15 years: 20 15 to 25 years: 395 25 to 45 years: 240 45 to 65 years old: 50 65 years or older: 10
Marital status	Unmarried: 665 Married: 40 Divorced: 10 Widowed: 5

Migration

Table 16

Origin of immigrant populations	Number of immigrants
Western	130
Non Western	270
Morocco	40
Netherlands Antilles and Aruba	15
Suriname	70
Turkey	25
Other non-western	130

Income (CBS, 2015)

According to National Income Distribution by municipality and district, 2015. The average personal income per inhabitant of private household in Amstel III is 49,900 Euro in 2015, which is almost two times of the average level in Amsterdam (26,900 Euro per inhabitant). However, the percentage of private households that belong to the 40% households with the lowest disposable is 49.1%, and the percentage of private households belonging to the 20% households with the highest disposable income is 16.7%. This reveals the fact that there is a slight polarization between the rich and the poor in this area. Furthermore, according to CBS (2019), there are at least 40 people that live in the area receiving different types of social benefits, such as unemployment benefits, social assistance benefits, disability benefit, and old age pension.

Households

Table 17

Characteristics	Data
Total number of households	565
Type of households	Single households: 350 Households without children: 25 Households with children: 20
Average household size	1.1

Type of houses

Table 18

Characteristics	Data
Type of houses	Percentage single-family house: 12 Percentage of multi-family dwelling: 88
Occupancy rate of houses	97%
Ownership	For sale: 2 Rental: 98 Owned by other landlords:98
Construction year	Built before 2000: 11 Built from 2000: 89

APPENDIX C. DATACENTERS IN AMSTEL III

(Equinix. 2020)

Table 19

Datacenter	Description
AM1 &AM2	Amsterdam AM1 and AM2 data centers and Internet Exchange point located at Laarderhoogtweg with vital peering opportunities suitable for mission-critical interconnection and colocation services.
AM5	AM5 is located in a prime city center location offering connectivity to a thriving and leading carrier neutral digital ecosystem.
AM7	-
AM11	Amsterdam AM11 data center and Internet exchange point is focused on international business and provides connectivity to extensive ecosystems to meet the demand for network exchange services. It is an entry point for cloud providers and provides peering for IP traffic.

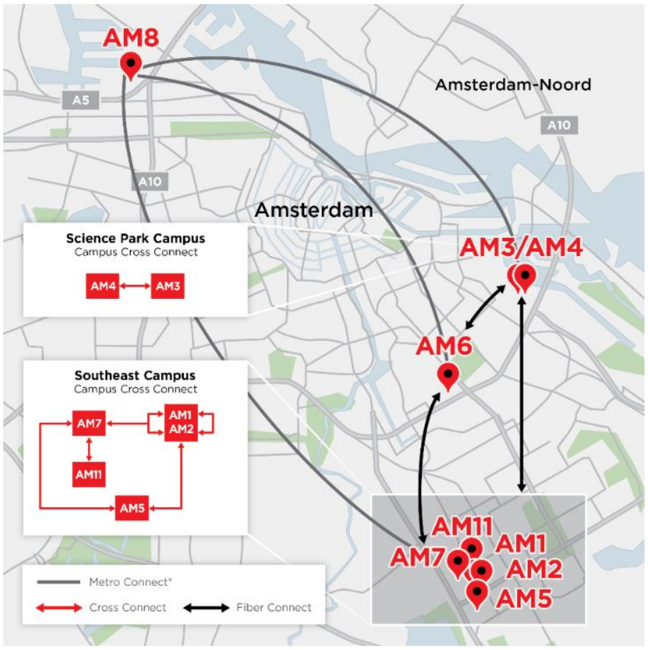

Figure 19

Smart city heating nets in Amstel III

Table 20

Type of heating network	Temperature range
High temperature network	90-70 ℃
Medium temperature network	70-40 ℃
Low temperature network	40-20 ℃
Very low temperature network	< 20 ℃

APPENDIX D. JUDGEMENTS COLLECTION WORKSHOP

In this project, the judgements for the CIB matrix construction are mostly obtained through the workshop that is held during the weekly meeting of the city of Amsterdam on September 23rd, from 11.00 to 12.30. Due to the Covid-19 situation, the workshop is held online via Teams.

At the beginning of the workshop, a presentation is given to introduce the motivation, objectives, approach, and progress of this project. Also, the tasks and key concepts for the workshop are explained to the participants. Due to the limitation of time for this workshop, the judgements are not filled by participants directly. By inviting them to share their views on some pre-prepared questions, their judgements concerning the interdependencies between some scenario factors are collected.

The questions are all formulated following the same structure as:

‘*If (future) Amstel III citizens think sustainability is important, how likely will it lead to them valuing affordability as important as well? Is that the case for everyone?*’

An example of how the participants’ statements from the workshop are translated into quantitative data in CIB matrix is presented in Section 4.3. The following part of this section will present other workshop contributions to the key sections in CIB matrix.

Impact of the importance of 'Affordability' on the importance of 'Sustainability' :

		Importance of 'Sustainability'		
		High	Medium	Low
Importance of 'Affordability'	High	0	0	0
	Medium	0	0	0
	Low	0	0	0

Information from the workshop:

1. It is possible that people think they are both very important. However, the order that people value ‘affordability’ and ‘sustainability’ may make a difference.

Interpretation: When people think the affordability of an energy alternative is acceptable, then if they find that the sustainability of this option is as well, their confidence in making this choice can be strengthened and vice versa. They are not necessarily conflicting with each other in the case of Amstel III. More sustainable heating networks can be cheaper at the same time. The priority that people evaluate those two values matters, but it depends on the specific network designs. It should be noted that the energy price is not the only factor that influences the importance of affordability, the expenses for appliances upgrade and house renovation (e.g. adding isolation to the roof and walls) shall be taken into account as well.

Judgements transformation: There is no clear evidence that energy consumers who think ‘affordability’ more or less important will have any preference regarding their evaluation for ‘sustainability’ of heating network designs. Therefore, ‘0’s are assigned to the cells in this section..

Impact of the importance of 'Affordability' on the importance of 'Openness' :

		Importance of ' Openness '		
		High	Medium	Low
Importance of 'Affordability'	High	-1	-1	2
	Medium	-1	0	1
	Low	1	0	-1

Information from the workshop:

1. Some energy users could not tolerate a monopoly energy supplier, while ‘affordability’ is still a dominant factor in this case.

Judgements transformation: Tradeoffs have to be made between the importance degrees of those two values that people may prefer to have fewer options for a lower price. ‘-1’s are assigned to the matrix to reflect these restricting relationships.

2. The correlation between ‘affordability’ and ‘openness’ can be complicated.

Interpretation: On one hand, more energy suppliers in the market can lead to competition and eventually lower the overall levels of energy price. On the other hand, more actors in the grids will create less efficiency and increase operation cost concerning, for instance, the extra investment in energy infrastructure. When the growth of the local energy market is slow, energy companies will show less interest to enter it (first round interview).

Impact of the importance of 'Affordability' on the importance of 'Fairness' :

		Importance of ' Fairness'		
		High	Medium	Low
Importance of 'Affordability'	High	1	1	-2
	Medium	1	0	-1
	Low	0	0	0

Information from the workshop:

1. In Dutch culture, ‘Fairness’ is one of the top-ranked values.

Judgements transformation: It would never be acceptable if people find that they have to pay more household budget for energy bill (distribution justice) than others in the neighbourhood, which could lead to strong social resistance of the implementation of some energy solutions. This is especially important for people who also attach great importance to ‘affordability’. Therefore, ‘high importance of affordability’ has a strong promotional influence on ‘importance of fairness’ as it is reflected in the matrix. Since two participants emphasized this unique phenomenon in the Netherlands during the workshop, ‘+1’ is assigned to the top-right cell in this section.

Impact of the importance of 'Openness' on the importance of 'Affordability':

		Importance of 'Affordability'		
		High	Medium	Low
Importance of 'Openness'	High	-1	-1	2
	Medium	-1	0	1
	Low	1	0	-1

Information from the workshop:

1. More open energy market can attract more energy suppliers to Amstel III and create more competitions.

Interpretation: However, a full competition market is not necessarily prior to the monopoly in this case. It is because of the unique characteristics of the district heating network that sometimes natural monopoly can have the advantages of ‘economies of scale’ especially in technical perspectives. For instance, the construction of transmission and distribution networks always involve significant investment and will need a long time to recover this cost. When the size of local energy market is limited, it would be more efficient and innovative to have only one monopoly company.

2. The interaction between ‘openness’ and ‘affordability’ is complicated and highly depends on specific situations.

Judgements transformation: In this case, more competitors may have more investments on the energy project and decrease the ‘affordability’ of local energy users by increasing the energy price in order to receive investment returns in a short period. Therefore, ‘-1’s are assigned to the top-right cells in this section to represent thses impacts.

Impact of the importance of 'Fairness' on the importance of 'Affordability':

		Importance of 'Affordability'		
		High	Medium	Low
Importance of ' Fairness'	High	-1	-1	2
	Medium	-1	0	1
	Low	1	0	-1

Information from the workshop:

1. In the Netherlands, ‘Fairness’ is inherently associated with ‘affordability’.

Judgements transformation: It will be considered as a fair network if the costs are distributed reasonably. However, when people have to make tradeoffs between those two values, they are always willing to give way on ‘affordability’ in exchange for a high level of ‘fairness’. Therefore in the matrix, restricting influences are filled in. ‘-1’s are assigned to the cells in the first row to present these tradeoffs.

APPENDIX E. SENSITIVITY ANALYSIS

Although the participants of interviews and workshop are experts in energy-related fields, their subjective judgements that are used as inputs for baseline CIB matrix is still too subjective and could bias results. To investigate whether the outcomes can derive much from the baseline matrix after adding new assumptions concerning the possible interdependencies between system factors. 5 sensitivities are investigated in this project. Sensitivity analysis matrix No.1 has been presented in Section 5.2 as an example. This appendix will present the rest 4 sensitivity analysis matrixs.

Impact of the importance of 'Affordability' on the importance of 'Sustainability':

In the baseline matrix, there is no direct influence between the ‘importance of affordability’ (IA) and the ‘importance of sustainability’ (IS). Therefore the correspongding section is filled with ‘0’s.

Table 21 The corresponding section in the baseline matrix

		Importance of ‘Sustainability’		
		High	Medium	Low
Importance of 'Affordability'	High	0	0	0
	Medium	0	0	0
	Low	0	0	0

In this sensitivity analysis No. 2, new assumption is made for the impacts from IA on IS:

When local inhabitants become more sensitive to the energy cost, and do not want to pay for the potential wrong decisions that are made on the sustainability heating system development, they are more likely to remain the existing network and do not desire any risks in RET innovation. In this case, high IA could have a restricting impact on the IS. The modification to the baseline CIB matrix and corresponding results are presented below:

Table 22 The section in the sensitivity analysis matrix No. 2

		Importance of ‘Sustainability’		
		High	Medium	Low
Importance of 'Affordability'	High	-1	0	1
	Medium	0	0	0
	Low	0	0	0

The outcome of sensitivity analysis matrix No. 2 is presented in Figure 19.

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th><th>Scenario No. 5</th><th>Scenario No. 6</th></tr>
<tr><td colspan="2">A. Importance of 'Environmental sustainability':
A1. High</td><td>A. Importance of 'Environmental sustainability':
A2. Medium</td><td colspan="3">A. Importance of 'Environmental sustainability':
A1. High</td></tr>
<tr><td colspan="2">B. Importance of 'Affordability':
B3. Low</td><td>B. Importance of 'Affordability':
B1. High</td><td colspan="3">B. Importance of 'Affordability':
B3. Low</td></tr>
<tr><td colspan="2">C. Importance of 'Openness':
C1. High</td><td>C. Importance of 'Openness':
C3. Low</td><td colspan="3">C. Importance of 'Openness':
C1. High</td></tr>
<tr><td>D. Importance of 'Fairness':
D1. High</td><td colspan="2">D. Importance of 'Fairness':
D2. Medium</td><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td></tr>
<tr><td colspan="2">E. CO2 Emissions:
E3. 95% reduction</td><td>E. CO2 Emissions:
E2. 55% reduction</td><td colspan="3">E. CO2 Emissions:
E3. 95% reduction</td></tr>
<tr><td colspan="2">F. Household income:
F1. Top 20%</td><td colspan="2">F. Household income:
F2. Medium</td><td colspan="2">F. Household income:
F3. Bottom 40%</td></tr>
<tr><td colspan="6">G. Technical lock-in:
G2. Weak</td></tr>
<tr><td colspan="6">H. Public participation:
H1. High</td></tr>
</table>

Figure 20 All the consistent scenarios for the sensitivity analysis matrix No. 2

5 of 6 consistent scenarios have a similar characteristics with the descriptions in Table (Section 5.2). Only one scenario shows high IA and low IO. Besides, the 'CO2 reduction' is estimated to have a lower level as a result of the compromise with energy cost.

Impact of the importance of 'Fairness' on the importance of 'CO2 emission' :

In the baseline matrix, there is no direct influence between the 'importance of fairness' (IF) and the 'CO2 emission' (CE). Therefore the correspongding section is filled with '0's.

Table 23 The section in the baseline matrix

<table>
<tr><td></td><td></td><td colspan="3">CO2 emission</td></tr>
<tr><td></td><td></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Importance of 'Fairness'</td><td>High</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Medium</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Low</td><td>0</td><td>0</td><td>0</td></tr>
</table>

In this sensitivity analysis No. 3, new assumption is made for the impacts from IF on CE:

The increasing public concerns on the distributive and procedural justice in the sustainable heating network construction will lead to endless arguments. The disputation will cause a delay in the progress of realizing energy neutral city district by the year of 2040. Therefore, the CO2 emssion objectives can be hindered by the high IF. The modification to the baseline CIB matrix and corresponding results are presented below:

Table 24 The section in the sensitivity analysis matrix No. 3

<table>
<tr><td></td><td></td><td colspan="3">CO2 emission</td></tr>
<tr><td></td><td></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Importance of 'Fairness'</td><td>High</td><td>-1</td><td>0</td><td>1</td></tr>
<tr><td>Medium</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Low</td><td>0</td><td>0</td><td>0</td></tr>
</table>

The outcome of sensitivity analysis matrix No. 3 is presented in Figure 20:

<table>
<tr><td>Scenario No. 11</td><td>Scenario No. 3</td><td>Scenario No. 10</td><td>Scenario No. 7</td><td>Scenario No. 6</td><td>Scenario No. 5</td><td>Scenario No. 1</td><td>Scenario No. 2</td><td>Scenario No. 9</td><td>Scenario No. 8</td><td>Scenario No. 12</td><td>Scenario No. 4</td><td>Scenario No. 13</td><td>Scenario No. 14</td><td>Scenario No. 15</td></tr>
<tr><td colspan="4">A. Importance of 'Environmental sustainability': A3. Low</td><td>A. Importance of 'Environmental sustainability': A2. Medium</td><td colspan="2">A. Importance of 'Environmental sustainability': A1. High</td><td colspan="2">A. Importance of 'Environmental sustainability': A2. Medium</td><td colspan="3">A. Importance of 'Environmental sustainability': A1. High</td><td colspan="3">A. Importance of 'Environmental sustainability': A3. Low</td></tr>
<tr><td>B. Importance of 'Affordability': B2. Medium</td><td colspan="14">B. Importance of 'Affordability': B3. Low</td></tr>
<tr><td>C. Importance of 'Openness': C2. Medium</td><td colspan="14">C. Importance of 'Openness': C1. High</td></tr>
<tr><td colspan="10">D. Importance of 'Fairness': D1. High</td><td colspan="2">D. Importance of 'Fairness': D2. Medium</td><td colspan="3">D. Importance of 'Fairness': D1. High</td></tr>
<tr><td colspan="15">E. CO2 Emissions: E3. 95% reduction</td></tr>
<tr><td>F. Household income: F3. Bottom 40%</td><td>F. Household income: F1. Top 20%</td><td>F. Household income: F3. Bottom 40%</td><td colspan="3">F. Household income: F2. Medium</td><td colspan="2">F. Household income: F1. Top 20%</td><td colspan="3">F. Household income: F3. Bottom 40%</td><td colspan="2">F. Household income: F1. Top 20%</td><td>F. Household income: F2. Medium</td><td>F. Household income: F3. Bottom 40%</td></tr>
<tr><td colspan="15">G. Technical lock-in: G2. Weak</td></tr>
<tr><td colspan="12">H. Public participation: H1. High</td><td colspan="3">H. Public participation: H2. Medium</td></tr>
</table>

Figure 21 All the consistent scenarios for the sensitivity analysis matrix No. 3

The outcome of sensitivity analysis matrix No.3 has significant difference from the baseline matrix in terms of the IS. Almost half of consistent scenarios show low IS in the future. The cause of this value change in 'Environmental sustainability' can be investigated in the CIB matrix. Figure shows that the only direct impact that the IS can receive is from the CE. When the CE takes the descriptor state of '95% reduction', none of the scenario's other elements supports or contradicts the assumption that the IS is low in the future. In fact, this assumption ('low') of IS and the alternative assumptions ('high' and 'medium') all have the impact score 0, which means none of the alternative assumptions is more plausible than the selected (i.e., higer impact score). Thus, the selected assumption can be assessed as being consistent.

In the real-world case of the heating network Amstel III, it can be interpreted as: when the living environment is improved markedly (95% CO2 reduction), it is possible that local inhabitants will care less about the 'Sustainability' in the district heating grid, and have more concerns for the fulfilment of other values. For instance, the distributive and procedural justice in the decision-making of RET project.

Impact of the importance of 'Affordability' on the importance of 'Openness':

In the baseline matrix, it is assumed that high IA will weakly restrict the high or medium IO.

Table 25 The section in the baseline matrix

		Importance of ' Openness '		
		High	Medium	Low
Importance of 'Affordability'	High	-1	-1	2
	Medium	-1	0	1
	Low	1	0	-1

In this sensitivity analysis No. 4, new assumption is made for the impacts from IA on IO:

The ‘Affordability’ becomes a dominant value for the social acceptance of sustainable heating solutions. Other values will have to make way for the fulfilment of ‘Affordability’, especially for the ‘Openness’ that could create extra costs. To reflect that high IA may have more strongly restricting impact on high or medium IO, the scensitivity analysis matrix No.4 has been modified as below:

Table 26 The section in the sensitivity analysis matrix No. 4

		Importance of ' Openness '		
		High	Medium	Low
Importance of 'Affordability'	High	-2	-1	3
	Medium	-1	0	1
	Low	1	0	-1

The outcome of sensitivity analysis matrix No. 4 is presented in Figure 21:

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th><th>Scenario No. 5</th><th>Scenario No. 6</th></tr>
<tr><td colspan="6">A. Importance of 'Environmental sustainability':
A1. High</td></tr>
<tr><td colspan="5">B. Importance of 'Affordability':
B3. Low</td><td>B. Importance of 'Affordability':
B1. High</td></tr>
<tr><td colspan="5">C. Importance of 'Openness':
C1. High</td><td>C. Importance of 'Openness':
C3. Low</td></tr>
<tr><td>D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td colspan="2">D. Importance of 'Fairness':
D2. Medium</td></tr>
<tr><td colspan="6">E. CO2 Emissions:
E3. 95% reduction</td></tr>
<tr><td colspan="2">F. Household income:
F1. Top 20%</td><td>F. Household income:
F2. Medium</td><td colspan="3">F. Household income:
F3. Bottom 40%</td></tr>
<tr><td colspan="6">G. Technical lock-in:
G2. Weak</td></tr>
<tr><td colspan="6">H. Public participation:
H1. High</td></tr>
</table>

Figure 22 All the consistent scenarios for the sensitivity analysis matrix No. 4

Most of the consistent scenarios do not show much difference from the baseline model except the Scenario No. 6, which has lower IO in exchange for a higher IA. Besides, the household income level in this scenario is also relatively low. This scenario implies that for the inhabitants with lower income (e.g., social housing), they are willing to compromise with 'Openness' of the heating network to have the energy service that they can afford.

Impact of the importance of 'Fairness' on the importance of 'Affordability':

The baseline model assumed that the IF has weakly restricting impact on high or medium IA.

Table 27 The section in the baseline matrix

<table>
<tr><td colspan="2"></td><td colspan="3">Importance of 'Affordability'</td></tr>
<tr><td colspan="2"></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Importance of ' Fairness'</td><td>High</td><td>-1</td><td>-1</td><td>2</td></tr>
<tr><td>Medium</td><td>-1</td><td>0</td><td>1</td></tr>
<tr><td>Low</td><td>1</td><td>0</td><td>-1</td></tr>
</table>

However, during the workshop, two participants both emphasized that in the context of Dutch culture, this effect could be enhanced. Therefore, the impact score in this section is modified to reflect more strongly influential relationships between IF and IA:

Table 28 The section in the sensitivity analysis matrix No. 5

<table>
<tr><td></td><td></td><td colspan="3">Importance of 'Affordability'</td></tr>
<tr><td></td><td></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Importance of ' Fairness'</td><td>High</td><td>-2</td><td>-1</td><td>3</td></tr>
<tr><td>Medium</td><td>-1</td><td>0</td><td>1</td></tr>
<tr><td>Low</td><td>1</td><td>0</td><td>-1</td></tr>
</table>

The outcome of sensitivity analysis matrix No. 5 is presented in Figure 22:

<table>
<tr><th>Scenario No. 1</th><th>Scenario No. 2</th><th>Scenario No. 3</th><th>Scenario No. 4</th><th>Scenario No. 5</th></tr>
<tr><td colspan="5">A. Importance of 'Environmental sustainability':
A1. High</td></tr>
<tr><td colspan="5">B. Importance of 'Affordability':
B3. Low</td></tr>
<tr><td colspan="5">C. Importance of 'Openness':
C1. High</td></tr>
<tr><td>D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td><td colspan="2">D. Importance of 'Fairness':
D1. High</td><td>D. Importance of 'Fairness':
D2. Medium</td></tr>
<tr><td colspan="5">E. CO2 Emissions:
E3. 95% reduction</td></tr>
<tr><td colspan="2">F. Household income:
F1. Top 20%</td><td>F. Household income:
F2. Medium</td><td colspan="2">F. Household income:
F3. Bottom 40%</td></tr>
<tr><td colspan="5">G. Technical lock-in:
G2. Weak</td></tr>
<tr><td colspan="5">H. Public participation:
H1. High</td></tr>
</table>

Figure 23 All the consistent scenarios for the sensitivity analysis matrix No. 5

This sensitivity has the exactly same result as the baseline model. Therefore, the impact from this adjustment can be safely disregarded.

APPENDIX F. INTERVIEW DESIGN

Value conceptualization - characteristics of the district heating system

Interview introduction

For the purpose of reducing the greenhouse gas (GHG) emissions based on National climate agreement, the city of Amsterdam is taking the initiatives to investigate how to push a district solution for the construction of more sustainable energy systems. Amstel III is one of pilots in Amsterdam Southeast that is pursuing sustainability in its future energy networks development. For all new constructions in this area, both residential and non-residential construction, permit applications must meet the requirements for Nearly Zero-Energy Buildings (BENG) from 1 January 2021. These requirements arise from the Energy Agreement for Sustainable Growth and from the European Energy Performance of Buildings Directive (EPBD). This research is going to employ a scenario analysis method to identify the value conflicts that exist in the sustainable energy systems in order to assess social acceptance (or public resistance) of new energy network construction projects in Amstel III. We conduct this interview to collect opinions and information from experts that can assist to conceptualize values that will be used in assessment framework for social acceptance in our model. A questionnaire (https://forms.gle/YJkWPr91zRC4Qb2D7) is also made for participants who do not have sufficient time for the whole interview (which normally takes 60 minutes). It will take 20~30 minutes to finish the questionnaire, which includes 4 sections. Each section contains a value that needs be conceptualized based on the personal understanding of participant.

Table 1 Descriptors for 'Sustainability'

Value: sustainability
1. Definition of Sustainability Question: - How would you define the value 'Sustainability' based on your role in this project? Indication for answers: - Stakeholders in energy transition involves: municipality of Amsterdam, project developers, data centers, citizens, energy sources. Different stakeholders may have different ideas on the same value. - For municipality, the 'Sustainability' that they are pursuing could be 'Environmental friendly'; for end-users, 'Sustainability' could mean 'High-efficiency'.
2. Factors defining sustainability (Descriptors) Question: - Which factors do you think can contribute to the fulfillment of value 'Sustainability' in Amstel III? Examples: - Type of energy: what is the type of energy that each company demands? Whether this will

have an impact on their fulfillment of value 'Sustainability'? - Energy infrastructure: what are the current energy infrastructures that companies in Amstel III have? Will different types of infrastructures influence their acceptance of new energy networks construction considering the value 'Sustainability'? - Annual energy consumption: How much energy each company in Amstel III consume every year? - Sustainability consciousness: will the sustainability consciousness of decision makers affect the levels of value? - Price sensitivity: how sensitive is each decision maker to the energy price?
3. Options for each factor (Descriptor States) Question: - What states or levels will you assign to each descriptor from the last question? Examples: A. Type of energy that is consumed A1. Heat A2. Cold A3. Both heat and cold A4. Electricity B. Energy infrastructure B1. Facility 1 B2. Facility 2 C. Energy demand C1. High (more than 50,000 KWh electricity) C2. Medium (between 15,000 KWh and 50,000 KWh) C3. Low (below 15,000 KWh) D. Sustainability consciousness D1. High D2. Medium D3. Low E. Sensitiveness to the price E1. High E2. Medium E3. Low

Table 2 Descriptors for 'Affordability'

Value: affordability
1. Definition of Affordability Question: - How would you define the value 'Affordability' based on your role or interests in this project? Probes: - Not only the affordability for end-users in the form of monthly energy bills, but also the cost

for other parties that are involved in energy systems, e.g. energy suppliers.
2. Factors defining Affordability (Descriptors) Question: - Which factors do you think can contribute to the fulfillment of value ‘Affordability’ in Amstel III? Examples: - Annual revenue: will annual revenue of each company have an impact on their affordability of energy in Amstel III? - Annual expenditure: can annual expenditure of each company indicate their affordability of energy in Amstel III?
3. Options for each factor (Descriptor States) Question: - What states or levels will you assign to each descriptor from the last question? Examples: A. <u>Annual revenue</u> A1. High A2. Medium A3. Low B. <u>Annual expenditure</u> B1. High B2. Medium B3. Low

Table 3 Descriptors for ‘Openness’

Value: openness
1. Definition of Openness Question: - How would you define the value ‘Openness’ based on your role or interests in this project? Probes: - In some cases, energy infrastructure operators can have very strict terms to energy suppliers and consumers who want to co-operate with them and use their energy transmission networks. Therefore, negotiations are required among different parties in consideration of the ‘Openness’ of the energy systems.
2. Factors defining Openness (Descriptors) Question: - Which factors do you think can contribute to the fulfillment of value ‘Openness’ in Amstel III? Examples: - Ownership of offices - Type of offices: whether the type of office for each company will influence their openness to sustainable energy networks?
3. Options for each factor (Descriptor States) Question:

- What states or levels will you assign to each descriptor from the last question? Examples: A. Ownership of office A1. Self-owned A2. Short term rent (less than 5 years) A3. Long term rent (at least 5 years) B. Type of office B1. Traditional office B2. Contiguous working spaces B3. Co-working Spaces B4. Shared Office Space B5. Shared Office Space

Table 4 Descriptors for 'Fairness'

Value: fairness
1. Definition of Fairness Question: - How would you define the value 'Fairness' based on your role or interests in this project? Probes: - Since different parties can have different interests, it is important to think through the consequence of violating the interests of some stakeholders in energy transition.
2. Factors defining Fairness (Descriptors) Question: - Which factors do you think can contribute to the fulfillment of value 'Fairness' in Amstel III? Examples: - Size of company: whether the size of company can influence their choice on energy network plans? - Are there any unforeseen circumstances that can cause different fulfillment of value 'Fairness'?
3. Options for each factor (Descriptor States) Question: - What states or levels will you assign to each descriptor from the last question? Examples: A. Size of company A1. Large A2. Medium A3. Small

Research interview on the social value changes in the renewable energy system in Amstel III

This interview will be conducted as part of the master graduation project by Huayi Sun from Delft University of Technology, which investigates the acceptability of the utilization of waste heat in a low-temperature network in Amstel III. All the information acquired through the interviews will remain confidential and will not be shared without permission from interviewees.

Research backgrounds:

We are conducting this interview as part of our research to increase the understanding of the acceptable energy solutions for all the stakeholders that are involved in energy grids of Amsterdam Southeast. The research project that we are working on is to employ a scenario analysis approach to investigate how the importance of social and moral values in energy systems (such as affordability and distributive justice) may change over time, as a result of the divergent tendencies in the characteristics of the neighbourhood (e.g. household income). Your expertise and experience can help us to identify the key influential factors and measure tradeoffs between conflicting values.

At present, the city of Amsterdam hopes to enhance the cooperation of different stakeholders for the energy transition in Amsterdam Southeast (track 3). In order to meet the CO2 reduction objective by the year of 2040, more sustainable energy sources (e.g. data heat from Equinix and soil energy) will be utilized for cooling and heating buildings in the area.

*The city of Amsterdam is using four types of social values as indicators to measure the public acceptance of sustainable energy system, including **Sustainability**, **Affordability**, **Openness**, and **Future-proof**. According to our previous survey, '**Fairness**' (distributive justice) is also considered as an important value by the local inhabitants (Table 1). In our research, a scenario analysis model is employed to simulate the conflicting interests and tradeoffs in the current district heating system. The outcomes of the (computation) model indicates that there are several consistent scenarios in the context of LT network development in Amstel III, which means this energy solution can be acceptable in the future.*

Table 1 Acceptability Index of sustainable energy solutions

Values	Definition
Environmental sustainability	The system meets its carbon obligation, which is regulated by the law. (55% reduction by 2030 and 95% reduction by 2050)

Affordability	Costs from the system are paid by energy consumers with a reasonable amount of their budget.
Openness	The system has no lock-in in technology or market for energy suppliers and end-users.
Fairness	The system provides equitable access to energy for local inhabitants and keeps distributive justice and procedural justice in energy transition processes.

However, different stakeholders that are involved in this heating system have different interests and energy demands, and 'acceptability' shall also consider the needs from other parties' perspective besides local inhabitants and the city of Amsterdam. Today's discussion intends to explore more on the potential risks/drawbacks that the LT networks in the future may have in failing to fulfill social values, compared with the existing HT (MT in the future) network, especially from the technical and commercial designs perspective.

Topics lists:

Before start

- *What role does the organization/company that you work for see itself in for the provision of data heat/construction of LT network in Amstel III (Amsterdam Southeast)?*
- *What are your concerns/expectations for the future construction of (LT) heating networks in Amstel III (Amsterdam Southeast)?*
- *Do you have any conflicts or convergence with other stakeholders (such as the city of Amsterdam, Vattenfall, and Firan) in the heating supply system?*

Sustainability

- Based on your own knowledge or experience, can you think of any potential risks for the LT network that may cause a decrease in the sustainability in Amstel III (Amsterdam Southeast)?
  Examples:
  1. Insufficient capacities for the cooling demand in the area.
  2. The potential conflicts between the decreasing machine temperature which is a result of technology innovation and the heating supply from data centers in the future.

Affordability

- Is there any potential risk for the LT network that may increase the financial burden on most of the stakeholders in the system?
  Example:
  1. The failure of insulation system of buildings may cause more electricity consumption.

Openness

- Do you see any drawbacks of a more open heating energy system?
  Example:

    1. Low efficiency

Fairness

- Is it still possible that all stakeholders and local inhabitants can participate together in the decision-making process, and even have a share in the LT network In Amstel III (compared to the case of windmill)?
  Example:

    1. The rapid developments in the area gives little time to arrange such thing.

Other values

- Which are the biggest obstacles that hinder the sustainable energy transition in Amsterdam Southeast?
  Are there more market barriers or technical challenges?