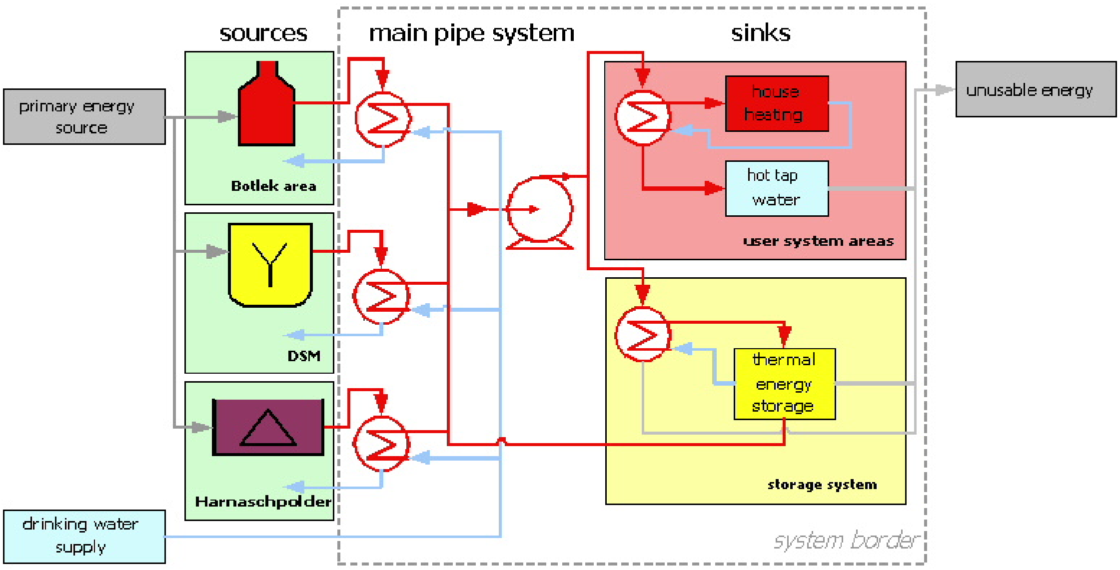
Utilization of waste energy for residential heating in Delft

Basis of Design for a city heating system



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Foreword

This report forms the first part of a design project about the design of a city heating system in Delft with the use of waste heat. In this first part we work towards a Basis of Design. This Basis of Design consists of a list of requirements and a first sketch of the system. In the second phase we will further develop the design.

We would like to thank our supervisors, M. Houwing, J. Koppenjan, J. Groenewegen and P. Jacobs for their time and suggestions. We would also like to thank P. Rommens from Delft municipality for his contribution.

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1 Introduction

After the ratification of the Kyoto protocol in 2002 the Dutch government has developed incentives to reduce greenhouse gas emissions. Based on these policies the municipality of Delft has formed its own policy concerning the reduction of greenhouse gas emissions within their municipality and is therefore exploring the possibilities of sustainable city heating systems.
Delft has outlined its policy for increasing efficiency of energy use in its 3E climate plan (Delft Municipality, 2003). The Trias Energetica concept (Ecofys, 2005) defines three ways to achieve this goal: maximize the use of sustainable energy sources, use non-renewable energy sources efficiently and/or minimize energy use. Delft considers a solution to increase the efficiency of the use of non-renewable energy: the use of (industrial) waste heat for city heating. Delft municipality, the problem owner of this design project, is exploring the possibilities for this type of systems. The start-up research question for this project is:

Which energy system can the municipality of Delft best apply for city heating with waste heat?

In this report, we follow a structured approach aimed at identifying a basis of design for such a system. This basis of design will guide us in the second phase of this project, i.e. the actual design of a city heating system.

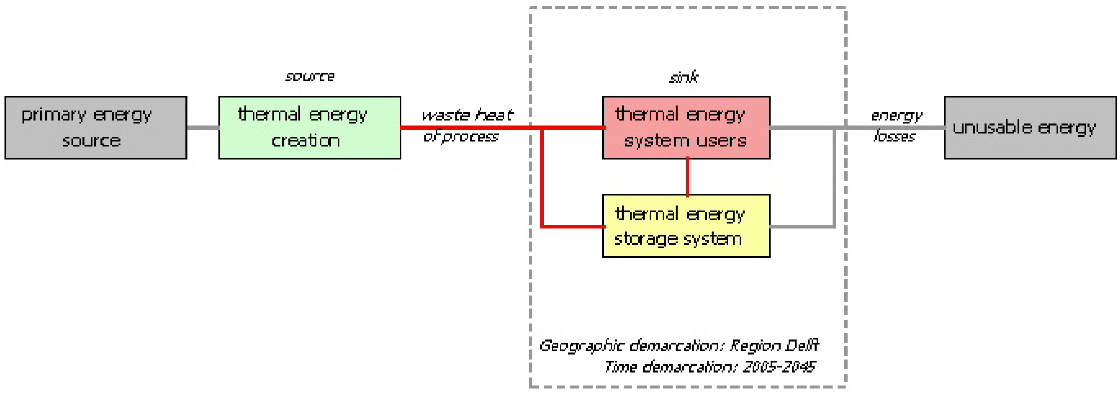

Figure 1. Generic system diagram of a city heating system in Delft.

In Figure 1 we see in general terms the main objects of such a system. First there is a primary energy source which is used in a process, thereby creating some form of waste heat. This heat is formed as a currently unused byproduct in a process called thermal energy creation. This heat is brought to users and/or storage. Some of the energy which reach users and storage will be unusable, due to low temperature or energy losses to the environment. The chosen demarcation will be explained in paragraph 3.3.
The city heating to be designed can be described as a complex system, with a distinct public interest. More specifically, it can be described as a multi-actor system. The system is neither designed, nor used in a vacuum. Its functioning will be dependent of the actors using, operating, maintaining and regulating the system. This includes users, suppliers of heat, system operators, political actors, setting an institutional framework, etc. These groups of actors may have different or even conflicting interests. Therefore, a multi-actor system is not only characterized by technological complexity, but also by another dimension of complexity, i.e. its multi-actor context.
The designer of such a multi-actor system needs to take into account this multi-actor setting. In order to assure a successful design, involvement of actors early in the design process is essential.

Therefore, the design will not only focus on the technical design, but shall also incorporate an institutional design and a process design (regarding decision-making aspects).

The deliverable of this report is a basis of design. A basis of design is an overview of performance indicators at system level, the design space and the goals and constraints the design will have to meet. It will encompass technical, institutional and process aspects. In order to come to this basis of design, the following steps will be conducted. First, we perform a problem analysis. This will lead to a problem definition and a list of the main criteria for the design. Second, we perform several analyses (an institutional analysis, a stakeholder analysis and a technical analysis). Third, we derive a broad design space. Fourth, we describe the requirements that the design will have to meet. Fifth, we select a design alternative based on the main criteria. This design alternative will be developed in the second phase of this project: the design itself.

The report is structured as follows. We start in Chapter 2 with a description of the methodologies used in this report. In Chapter 3, we analyze the design problem in more detail. This will provide a better understanding of the design assignment and the main performance indicators for the system. In Chapter 4, we outline the design space for the city heating system. The technical part of the design space will comprise a description of sources and sinks of energy for the city heating system, as well as a general description of the technology to be used. The institutional design space will cover institutional arrangements that the system can have. The process design space will consist of the possible process arrangements to be made for a real life design and decision making process. In Chapter 5, we will derive the system requirements. This will result in a list of goals and constraints for the system. In Chapter 6, we perform a quick scan of design alternatives. The most promising design alternative shall be chosen for the remainder of the project.

The working arrangements followed in this part of the design project can be found in Appendix 1.

2 Methodology

2.1 Description of a meta-methodology

The design process is based on systems thinking. The artifact to be designed is not a single element, but an entire system. As mentioned in the introduction, the design will comprise several elements: technical elements, institutional elements and decision-making elements related to the design process. In Figure 2, we have illustrated how these elements are related. The substantive design will cover the technical as well as the institutional aspects of the system. Furthermore, because the design is executed in a multi-actor context, the design process will also be designed.

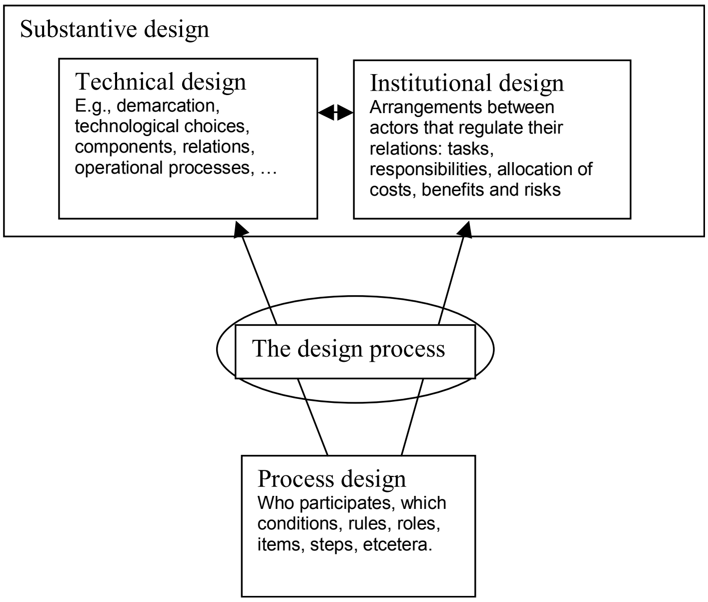

Figure 2. Elements of a multi-actor systems design. Figure 1 in Koppenjan and Groenewegen, 2004.

The meta model as developed by Westerberg et.al. (1997) (Figure 3) is a model that can be applied when designing multi-actor systems. The model prescribes which steps are to be undertaken to design a multi-actor system. Because it is designed at a general level, it allows the designer to choose which specific tools and models are applied to different stages and aspects in the design. This makes the model very useful for the design of different types of systems. Per step in the model that shall be undertaken, we will provide a description of the specific methodology used.

In this report, we will cover the gray part of the meta model. This consists of the development a list of requirements, the formulation of objectives and constraints and the development of the solution space. These steps will result in a Basis of Design. This will be point of departure for the second part of this project, i.e. the actual design of the city heating system. This second part corresponds to the 'second' part of the meta model, i.e. developing and executing tests and selecting alternatives.

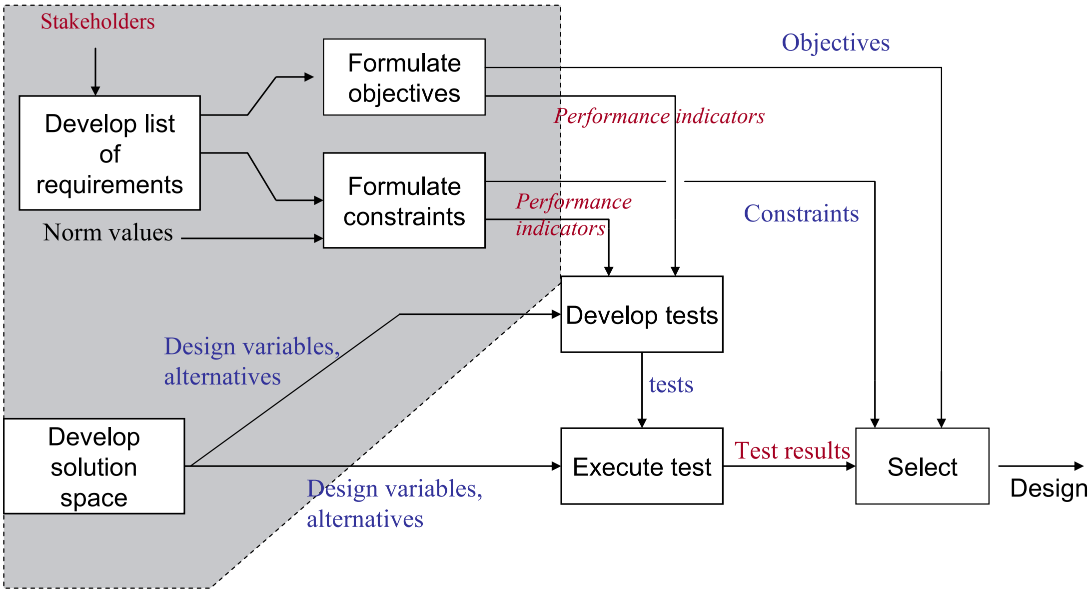

Figure 3. Meta Model (Adapted from Westerberg et al., 1997).

Besides the steps to be performed in the design process, the way of working should indicate by who and when these steps will be performed. In order to answer these questions, we will use a process management approach. The reason for this choice is that the design and use of the system takes place in a network, rather than in a hierarchical setting. Because of interdependencies, strategic behavior can be expected and the process will not be linear. Because of irregularities and unexpected events expected in the decision making process, project management is not considered useful and a process perspective is adopted. Advantages of using process management in this context are better support for the design, reduction of substantive uncertainty, enrichment of the problem definition and solutions, incorporation of dynamics, transparency and depolitization (see De Bruijn et al., 2002).

In this report, we focus on the list of requirements and on developing the solution space. In order to do this, we combine analytic and creative methods. An interview was held with Delft municipality. The findings of the actor and network analysis will be useful to derive requirements for the process and for the other design aspect (technical and institutional).

2.2 Limitations of an academic setting

A multi-actor systems design will be of better quality when it is designed in a multi-actor context. If actors are not involved in the design, there is a probability that not all their ideas, goals and constraints are taken into account. Also, the system may suffer limited acceptance when critical actors have the feeling that their interests are not represented accurately.

Unfortunately, since the design project is conducted in an educational setting, a process design with involvement of all relevant actors is not possible. However, it is useful to consider and describe the progression of the process design as it would occur in reality. This description will be given in the process design.
Normally, the design process would be conducted in cooperation with the actors that are critical in the design phase. Their participation would allow a complete description of requirements to the design. From these requirements, a selection can be made for a design alternative.
In this case however, we cannot perform the design in a multi-actor setting. Also, the design alternative chosen dictates the actors that are relevant for a process design. If we decide to use

heat from DSM, participation of DSM in the design is required. If we however choose to use heat from multiple user's, for example DSM and Delfluent, other interests and dependencies will be important and a very different process design would be suitable. Therefore, we cannot make a generic process design for the city heating system.
Because we want to find a creative solution, we choose to diverge and explore a broad design space. This implies that we cannot describe the process design thoroughly until we have decided upon a specific alternative for a city heating system.

3 Problem analysis

The goal of this chapter is to define the design problem and to uncover the general, high-level performance indicators for the design. We will first discuss these issues from the perspective of the problem owner, Delft municipality. Then, we will discuss the point of view of the actors Delft is dependent on for realization of the project.
We analyze the goals and reasons to participate in the project by decomposing a hierarchy of goals and the means to achieve these goals. These schematic representations can be found in Appendix 2. The conclusions are presented here.

3.1 Perspective of Delft municipality

After the ratification of the Kyoto protocol in 2002 the Dutch government has developed incentives to reduce greenhouse gas emissions. Based on these policies the municipality of Delft has formed its own policy concerning the reduction of greenhouse gas emissions within their municipality and is therefore exploring the possibilities of more sustainable city heating systems.

Delft has anchored its energy policy in the so-called 3D Sustainability Plan (Delft Municipality, 1999). It contains Delft's policy towards sustainable development of the city, where sustainable development comprises economic, ecologic and social sustainability. One of the main themes of the 3D Sustainability Plan is energy. The plan states Delft's two main objectives concerning energy use. The first objective is that the average energy use of households for heating in 2020 will be 60% of the energy use in 1999. The second objective is that energy from sustainable sources constitutes 15% of the total amount of energy used in Delft.

Delft has outlined its policy for increasing efficiency of energy use in its 3E climate plan (Delft Municipality, 2003). One of the goals defined in this plan is the wish to realize a reduction of CO_2 emissions with 33500 ton per year in 2012. The Trias Energetica concept (Ecofys, 2005) defines three ways to achieve this goal: maximize the use of sustainable energy sources, use non-renewable energy sources efficiently and/or minimize energy use. Delft considers a solution to increase the efficiency of the use of non-renewable energy: the use of (industrial) waste heat for city heating.

Delft's problem statement is: *Which energy system can the municipality of Delft best apply for city heating with waste heat, during the restructuring and construction of residential areas?*
The main performance indicators are:

- Costs per ton CO_2 savings
- Contribution to reduction of CO_2 emissions in Delft
- Total energy savings
- Total benefit for households – total costs for households
- Robustness of city heating system

3.2 Perspective of critical stakeholders

Delft municipality is heavily dependent on several stakeholders in order to make the project a success. These critical stakeholders have been identified in a stakeholder analysis (Appendix 2). First, housing corporations are very important. They own the buildings that the city heating system will be implemented in. Therefore, they can constitute a blocking power. Housing corporations in Delft include DelftWonen, DuWo, Vidomes and Vestia. Second, the parties that will act as heat suppliers, for example energy companies, are critical. Without their cooperation, no heat delivery is possible and a city heating system based on waste heat cannot be realized.

Third, the future network operator energy is a critical actor. It will be responsible for the infrastructure, heat delivery and billing. Likely, this network operator will be an energy company, for instance the current network operator Eneco. Fourth, the contractor that will build the city heating system is critical. However, he will be come critical in a later phase of the design project (for instance during detailed design, depending on the type of tendering chosen).
The problem statements and main performance indicators for the critical stakeholders are presented in Appendix 2.

3.3 Conclusion and demarcation

Based on the above, we define the design problem as follows:
Which energy system can the municipality of Delft best apply for city heating with waste heat, taking into account the interests of Delft and of the stakeholders that Delft is critically dependent of, i.e. the heat suppliers, the housing corporations and the future network operator?

The performance indicators that have been mentioned before will be combined with what Rouse (1991) refers to as measurement issues. According to Rouse (1991), making a successful design requires taking into account seven measurement issues in the early stages of the design process.
The first and foremost issue is viability. It must be demonstrated that the benefits of the system exceed the costs. As follows from paragraph 3.2, the benefits and costs must be in balance for each of the stakeholders (heat supplier, housing corporation and the future network operator).
A second issue is acceptance of the system by users. In this case, the users will be the inhabitants of houses that will be connected to the city heating system. Their interests are described in the stakeholder analysis (Appendix 2). The main goals with respect to this system is minimal cost increase, increase of comfort and quality of houses, maximum reliability of heat supply and minimal hinder from implementation.
A third issue is validation: does the system solve the problem? The problem definitions of the critical actors must be taken into account to answer this question.
A fourth issue is evaluation: does the system meet requirements? The requirements will be identified in a later chapter. During this identification, we must think how we would evaluate each requirement.
The last issues are demonstration, verification and testing. Demonstration is needed to observe people’s reaction to the system. Verification answers the question if the system has been put together as planned. Testing is concerned with the final functioning of the system. These issues will not be addressed during this design project. They can be dealt with in the later stages of the design process.

Based on the above, we will define a few high-level performance indicators. These will serve as criteria to choose a design alternative to further design in the second phase of this project. We have chosen four criteria that are essential to all critical stakeholders: robustness, total benefits – total costs, compliance to interests of critical actors, contribution to reduction of CO_2 emissions.

In Figure 1 in Chapter 1 we demarcated this project geographically and in time. Geographically we demarcate our research to the region of Delft. This demarcation is done because Delft municipality is the problem owner. The time demarcation is 40 years. First there is a development and implementation time of 5 years (until 2010) and then the system lifetime of 35 years (until 2045). A development and implementation time of 5 years is chosen because Delft municipality has formulated its energy goals in the 3E plan until 2012. Furthermore, Delft municipality can benefit from European subsidies if a project is realized before 2010 (Oosterwijk, 2005). A lifetime of 35 has been chosen because we consider 35 years a reasonable lifetime for equipment such as heat pumps, heat exchangers, heat appliances etc.

4 Design space

4.1 Design space for technical design

When browsing the design space for a sustainable city heating system, we initially try to identify many options for such a system. Based on this paragraph, different combinations of sources and sinks can be found. After describing a Basis of Design, we can choose one of these combinations for further design.

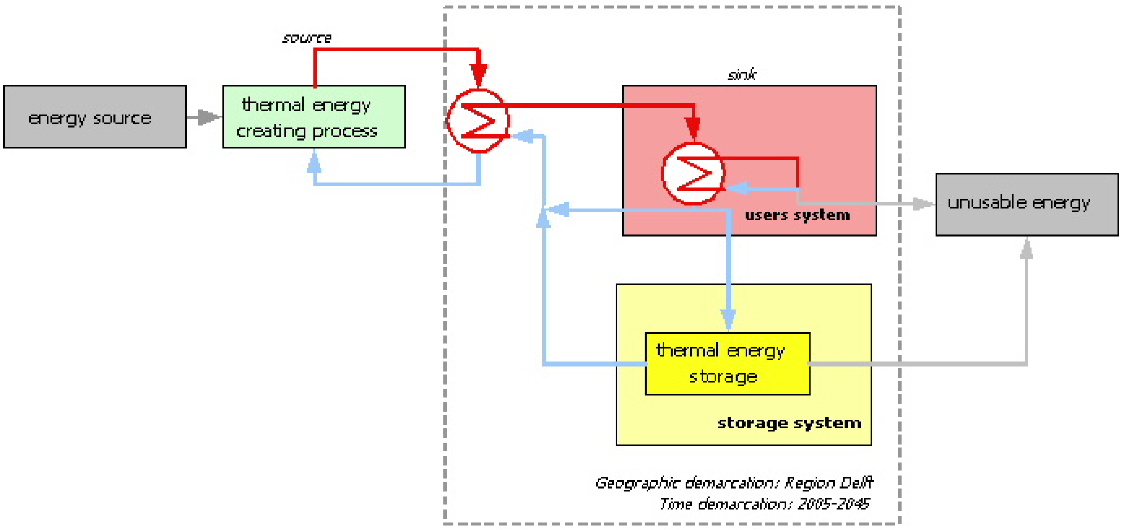

Figure 4. City heating system diagram. For a legend, see Appendix 3.

4.1.1 Technology

A city heating system provides heat for house heating and for hot tap water. Inside the house these cycles are separated. The temperature of the hot tap water should always be at least 66,5 ^{o}C for safety reasons (see Oosterwijk, 2005). It could be efficient to use different temperatures for heating and hot tap water. This would lead to a different configuration of heat flows, exchangers and pumps. Possibilities can be compared with respect to energy efficiency using pinch technology.

Two possible outcomes of a pinch technology are presented in Figure 5 and Figure 6. Heat pumps are not represented in these figures. A choice for technologies used and their placement will be made in the second phase of this project.

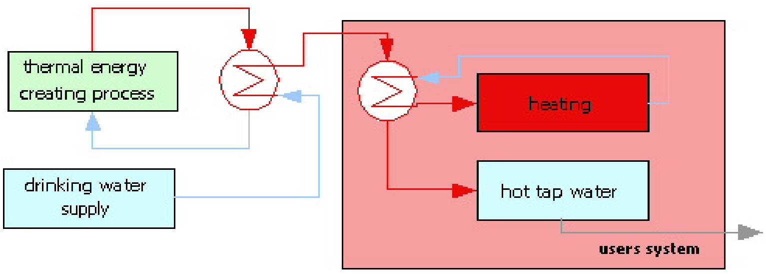

Figure 5. First possible configuration

A technical solution for a heating system can be high temperature or low temperature heating. Floor heating, and wall heating are both low temperature heating. Radiators are considered high temperature heating. Radiators function through radiation and convection of heat. They operate at a temperature of 90°C (Novem, 2002). Floor and wall heating have a higher share of radiation heating, allowing them to operate at lower temperatures (55°C), which makes them more energy efficient and more comfortable (Novem, 2002).

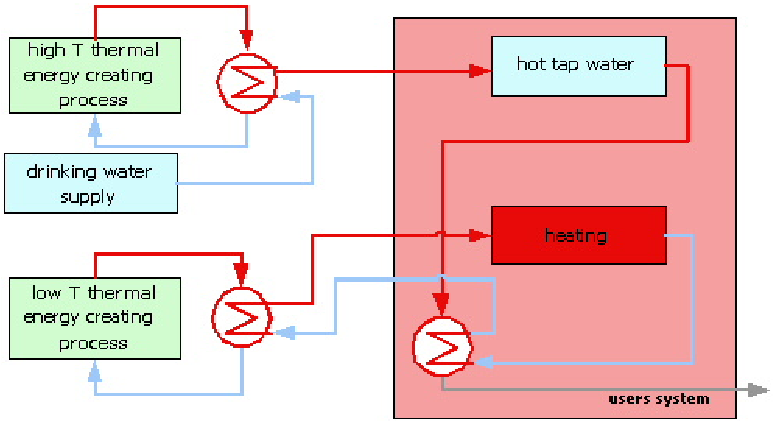

Figure 6. Second possible configuration

Heat flows naturally from a higher to a lower temperature. Heat pumps, however, are able to force the heat flow in the other direction, using a relatively small amount of high quality drive energy (electricity, fuel, or high-temperature waste heat) (see Heat Pump Centre).
Four types of heat pumps are available: one combined with a gas turbine, an electrical pump, a pump based on two steps absorption and one based on one step absorption (see Kempkes and de Zwart, 2002). The gas turbine heat pump and the electrical heat pump are the most promising heat pumps, from an economical and energetic perspective, therefore only these two will be further studied.

Heat is exchanged by using heat exchangers, which can be parallel pipes, the mixing of fluids or gasses.

4.1.2 Sources of energy

There are different types of energy sources that may be used for city heating. After the necessary transformations, thermal energy (heat), mechanical energy (from water or wind), and chemical energy may be used. Energy from fossil fuels is not considered as an option for city heating, because it is not a sustainable source of energy.

Thermal energy
Thermal energy can already be used for domestic heating with a relatively low temperature by using a heat pump. Thermal energy that may be used for city heating can be found in asphalt, greenhouses, aquifers and effluent streams from industrial processes.

Asphalt and greenhouses absorb solar radiation. The heat can be recovered and used for instance for city heating. The problem is that the availability of this energy source is highly seasonal. Most solar energy will be collected in summer, while the heat demand is higher in winter. It can therefore only be used in combination with energy storage (for instance in aquifers). According to ECN Beleidsstudies (2005), a market analysis conducted by Novem concluded that the energy generation potential of asphalt is marginal, because of system losses. Although most greenhouses are outside Delft municipal grounds, we will consider them in our search for alternatives.

Aquifers could be another source of thermal energy. According to Oxford University Press's Dictionary of Science (1999), aquifers are "deposits of rock that yield economic supplies of water […] as a result of their porosity or permeability". The energy contained in aquifer water can be utilized for city heating by using a heat pump. Water with higher thermal energy content can be extracted and the heat can be transferred to a heat pump. The opposite can be done also to use the aquifer as a heat storage facility. However, in Delft it is not possible to extract more energy from groundwater due to the groundwater use of DSM (Oosterwijk, 2005) and thus we will not consider taking energy from an aquifer. Possibilities for energy storage in aquifers will be considered in order to be able to overcome fluctuations in demand and supply.

A possible source of thermal energy is heat from industrial effluent streams (liquid or gaseous). Examples of industries with such streams are process industry, sewage treatment facilities, (gas fired) power plants.
An *industrial area* to take into consideration is the Port of Rotterdam: Maasvlakte (zone A in Figure 7), Europoort (zone B and C in Figure 7) and Botlek (zone D and E in Figure 7). It hosts a wide number of oil refineries and chemical companies. Distances can be overcome by using a large pipeline that will connect Rotterdam to Delft and that may serve several different sources. Industrial production plants around Delft are for instance DSM Gist, Calvé (a business unit of Unilever) and Pirelli. Contacts with Calvé and Pirelli have showed that they do not have useful effluent for a city heating system. DSM Gist's Delft site (zone G in Figure 7) consists of three plants: bakery ingredients, antibiotics and food specialties. DSM has expressed willingness to discuss allowing its wastewater to be used for city heating. However, they have not made any definitive decision whether or not to participate in the project (De Jonge, 2003). Moreover, DSM has announced that the antibiotics department will be closed in April 2005 (De Graaf, 2004). However, according to Haagsche Courant (2005), DSM now also considers selling its bakery ingredients department. After the closure of the antibiotics still 1/3 of the wastewater is produced (Oosterwijk 2005). Industrial effluent can be retrieved from energy plants and industrial production plants.
The main *sewage treatment plant* in the region around Delft is the AWZI of Delfluent (zone F in Figure 7). Heat can be recovered from sewage water before or after treatment. The first option is however is prohibited by the fact that sewage water treatment requires the water to be at a certain temperature. If it is colder (as will be the case when thermal energy is used for city heating), the treatment process will be less effective, requiring a larger plant or heating of the influent (Rommens, 2003a). Using sewage treatment influent as an energy source is therefore not very sustainable. Therefore, we will exclude this option and discuss only sewage water effluent.
Power plants can be found in the Port of Rotterdam area.

Mechanical energy
Mechanical energy can be converted to electricity with a turbine on site, which can for instance serve as a driving force for heat pumps. Mechanical energy can be retrieved from wind or water. Wind power is currently used to produce electricity, which is sold as so-called 'green' electricity. There are limited possibilities to generate hydropower around Delft. A possibility could be to use mechanical energy from sewage flows.

Chemical energy
Chemical energy can in principle be recovered from all substances. However, our goal is to use an energy source which is currently unused. Therefore we focus on waste. Most combustible household waste is currently utilized for electricity production in large-scale waste incinerators. Therefore, we do not consider this source of energy. Green household waste and agricultural waste however are collected separately from other types of waste. This could be transformed into biogas by fermentation. Biogas could serve as fuel for heating or for firing the heat pump.

4.1.3 Sinks of energy

In principle all residential areas could be equipped with a city heating system. However due to high investment costs and inconvenience for the inhabitants during implementation we choose to focus only on restructuring or new construction projects within the municipality Delft. If the energy source has abundant amounts of energy available, also other sinks around Delft municipality can be included.

Delft municipality is interested in city heating for residential areas. Seven residential areas in Delft will be constructed or restructured in the coming years: Harnascholder (1200 new houses; area 1 in Figure 7), Spoorzone (area 2 in Figure 7), Poptahof (area 3 in Figure 7), Wippolder (area 4 in Figure 7), TU Noord (area 5 in Figure 7), Voorhof (area 6 in Figure 7) and Buitenhof (area 7 in Figure 7). Next to city heating in residential areas, other sinks to consider are for example heating systems for sustainable business areas. Another possibility is to apply the recovered heat in greenhouses or (industrial) processes with average temperature heat demand. Because the design problem concentrates around city heating for residential areas, we will only consider the other sinks if the heat available from the sources exceeds the demand in the residential areas.

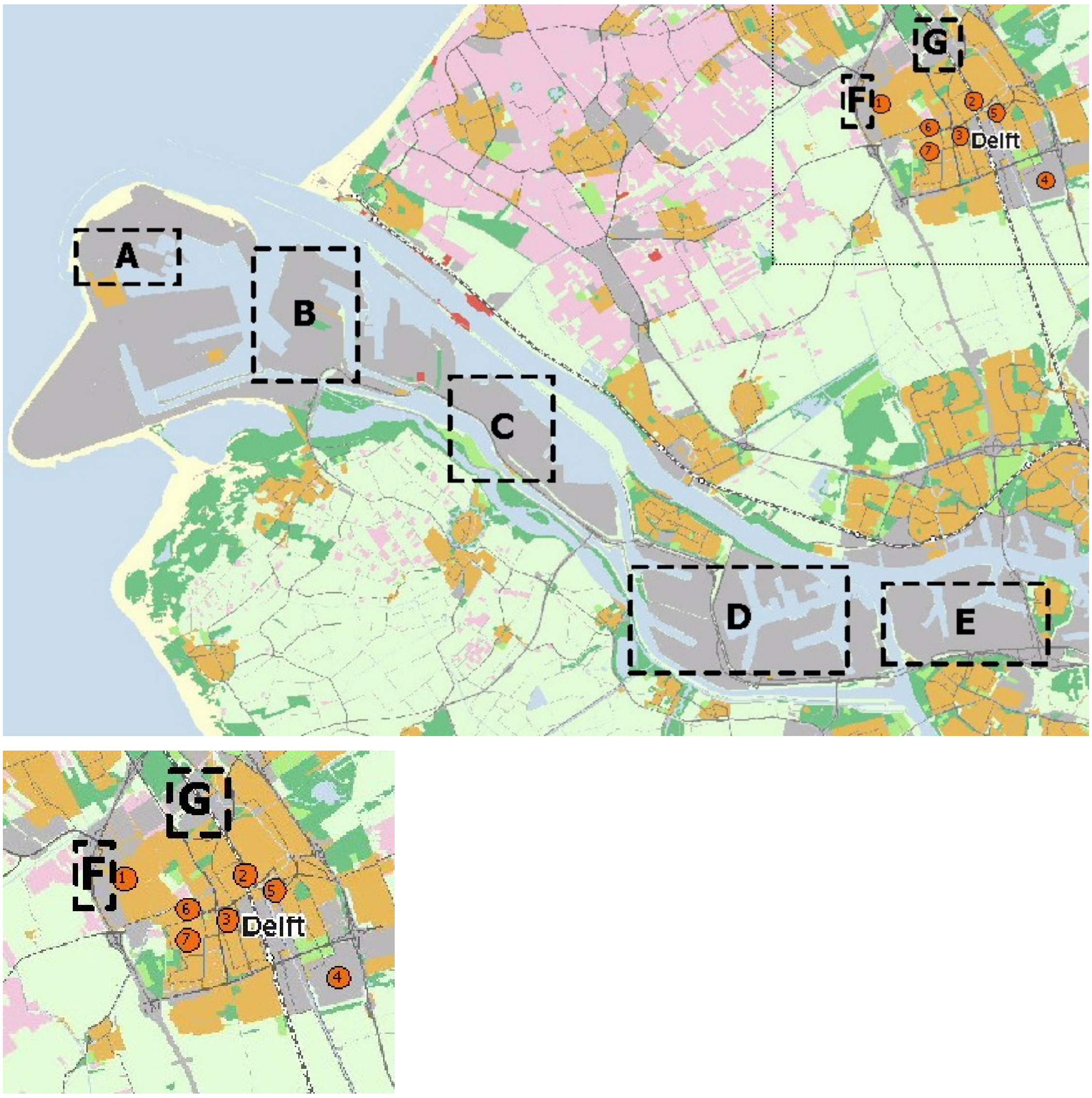

Figure 7. Sources and sinks for city heating system (incl. focus on Delft).

4.2 Design space for the institutional design

Creating a more sustainable city heating system is not just a technical design problem but also an institutional design problem. Because the technological energy system will not regulate itself, cooperation between the different parties and their networks is necessary to establish and maintain the system. To create this cooperation, coordination between all the actors in and around the system is vital. Therefore institutional arrangements have to be designed at different levels. Institutional arrangements are the arrangements between actors that regulate their relations, tasks, responsibilities, allocations, benefits and risks (Groenewegen and Koppenjan, 2004).

To find out about the different possibilities for the institutional design of the system, an analysis of the institutional system will be made. This is done by distinguishing four levels of analysis or design with regard to the functioning of complex (technological) systems. These levels of analysis are inspired by the so-called four-layer model of Williamson (1998). The four-layer model is useful because it covers institutional aspects on different levels; on the informal level, on the legal level, on the arrangements and agreements between (groups of) actors and on the lowest level, the actors themselves. By using the framework the institutional design will be as thorough and complete as possible. Of course stakeholder consultation is also an important way to determine and shape the institutional design, but this is not possible due to the academic setting of this project.

The institutional settings in the four levels change over time, but in table 1 (see Table 1) an overview is given of the situation now. In Appendix 4 the four-layer framework is further explained. The relation between the layers in the framework is a two-way relationship; for example the formal rules for tendering constrain the arrangements made at level three and the actors and arrangements of the higher levels influence the making of the laws on the formal level.

4.2.1 Institutional environment

Level one and two are also called the institutional environment of the system. Redesigning or changing the institutions at these levels is much more difficult and time consuming than changing the arrangements at level two. (see Groenewegen and Koppenjan, 2004). Therefore we consider the institutional environment here as given and will focus more on the design variables in the third and fourth level. We will thus assume that the main substance of the culture and laws regarding the design of the energy system will remain to exist within the write off time of the heat network, or at least not change in a way that the protection of the environment will become less important. Even if all the industry will start using a new clean fuel, the reuse of waste heat will still be useful. (see Rom-Rijnmond 2004, ch. 4). The policy documents and laws will be seen as constraints or limitations for the design of the energy system. The informal culture and values will be treated as guiding principles during the design process.

We will use the theory of New Institutional Economics (NIE) to further develop the design space on the third level, because this theory explains the institutional arrangements that coordinate interactions. It is based on a given institutional environment and actors that have bounded rationality (see Künneke en Koppenjan, 2004). Of course these two assumptions are theoretical and do not hold for the real world but still some notions from NIE are helpful for identifying decision variables and widening the design space. We will discuss Transaction Cost Economics (TCE), useful for determining the most efficient governance structures (level 3) and Property rights, to describe the ownership structures (level 4). We consider TCE a useful approach, because it allows to judge the efficiency of governance structures for a certain transaction, based on transaction costs as well as production costs. TCE also is at the core of the chosen NIE approach.

Table 1 Four-layer framework, based on Williamson (1998)

Four-layer framework	
Level 1 Culture and values	Environmental concern, taking responsibilities Conscience of limitation of resources Value of image; giving the right example Innovativeness is rewarded Poldermodel
Level 2 Laws and formal policy	Kyoto protocol 2003/87/EG: Greenhouse Gas emission trading 2004/17/EC: Public procurement procedures NMP 4 (national environmental policy) Beleidsplan Milieu en Water (provincial environmental policy) New policy on heat tariffs (Dte) 3E: Klimaatplan Delft (municipality's environmental policy)
Level 3 Institutional arrangements	Contacts, negotiations and agreements between Delft municipality, DSM and the HHR Delfland Subsidies, Tariff structures Governance: Public procurement procedures, ownership structures, governance structures
Level 4 Actors and games	Public parties: EU, VROM, EZ, V&W, NEa, Province Zuid-Holland, Delft municipality, municipalities around Delft (Rotterdam, Westland, Midden Delfland,), HHD, Warmtebedrijf Rotterdam, Private parties and interest groups DSM Gist, Delfluent, Botlek area, Project developers, Housing associations, Energy companies and network operator, TU Delft, EnergieNed, IPO, VNG, MKB Nederland, LTO Nederland, Platform Bewoners en Duurzaam Bouwen Research institutions ECN, Senter Novem, Infomil, RMNO

Original Institutional Economics is a theory that contradicts the assumption that the environment is given and tries to incorporate changes in the institutional environment (level 1 and 2) in the design and explanation of institutional arrangements. Trust and competence building play an important role in institutional economics as many relationships are based on dependencies between different actors. Even though we will not use this theory these notions should be kept in mind when designing the institutional system.

4.2.2 Institutional arrangements

For the description of the possible institutional arrangements (level 3 of the four layer framework), the arrangements made in a similar project (the project of Rom-Rijnmond) are taken as a starting point (see ROM- Rijnmond 2004). In order to be able to describe the different interactions necessary between parties we will look at the value chain of the heat network. This value chain is split up in three different parts; heat supply, heat transportation and maintenance of the main network and heat distribution to the houses (including distribution and supply). In the case of Rotterdam the Warmtebedrijf Rotterdam is set up to perform the tasks of the transportation company. In Figure 8 and Figure 9 the value chain of the new system is described with the help of a role and actor diagram and a revenue flow diagram. The three main activities in the network can be performed by different actors or can be integrated in one company, depending on which governance structure is most efficient. In the rest of this chapter the names of these activities; Heat suppliers, Transportation company and Distribution company will be used for indicating the activities that they perform. The structure of the revenue flows will be determined in the design phase of this project.

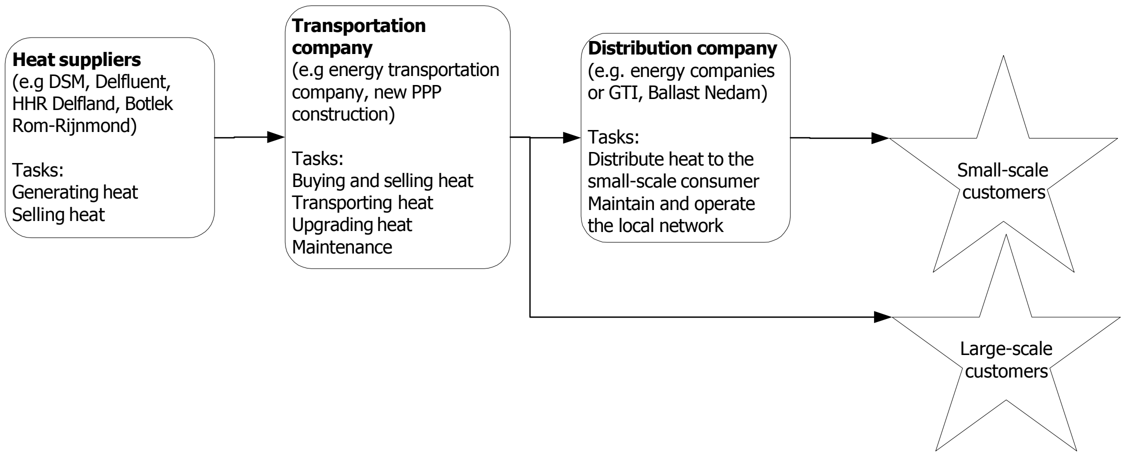

Figure 8. Actors and Roles in the value chain of the heat supply network

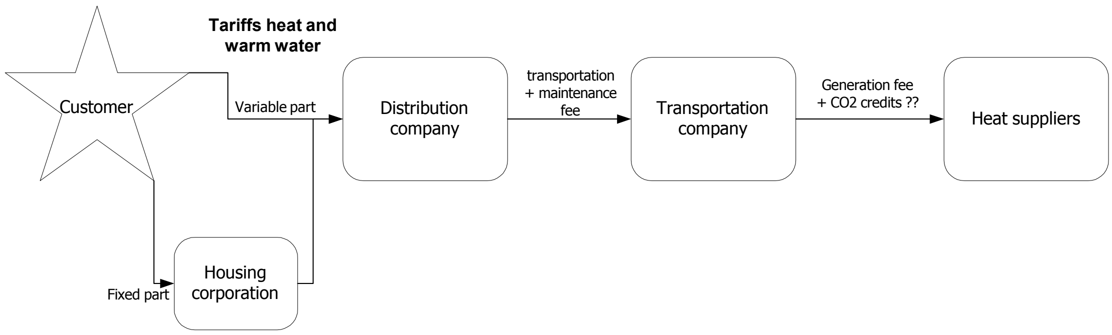

Figure 9. Possible revenue flows in the value chain of the heat supply network

Governance structures of transactions

Transaction Cost Economics will help to define the most efficient governance structures. TCE is an approach developed mainly by Williamson (1979) and Coase (1937) for explaining and predicting which of various institutional arrangements is most effective for a transaction. The transaction is characterized by the asset specificity, the frequency and the uncertainty of the transaction. Three examples of transaction governance structures are used here in the range from open market to an integrated hierarchy. These are; classical contracting or open market trading, neo-classical contracting, and relational contracts (see: Sartorius and Kirsten 2004, Chapter 3). The explanation of these governance structures can be found in Appendix 4. In Table 2 all the possible governance structures are listed for the different roles and interactions in the value chain. At some points there is only one possible optimal governance structure, however also factors from the process design have an influence on the optimal governance structures, so no definite choice is made yet.

The two main organizational choices that can be found in Table 2 are the choice whether the transportation company is a separate company or not and whether the distribution to the houses is done by a vertically integrated distribution and supply company or by two separate companies.

Table 2. Possible optimal Governance structures according to Transaction Cost Economics

Transactions/agreements necessary between:	Description	Transaction characteristics			Possible governance structures
		Asset specificity	Frequency	Uncertainty	
Delft Mun. with housing corporations, building contractors, heat suppliers	Startup agreement about organization of supply, transportation, maintenance	High	Low frequency for setup of the organizational solution, high frequency for transactions with the organizational solution	High	Relational contract: PPP construction or integration in other companies (hierarchy)
Heat suppliers with transportation company	CO_2 credits	High	Monthly	Medium	Neo-classical contract
	Payments	Low	High	Low	Classical contract
Network company and energy supply companies	Organizational setup of distribution company (vertically integrated or not)	High	Low	High	Relational contract or vertical integration (hierarchy)
Transportation company with distribution company and energy supply companies	Delivery specificities (tariffs, failures)	Medium	Low	Medium	Neo-classical contract, e.g. public procurement procedure
Transportation company with building contractors	Restructuring of houses, building of infrastructure	High	Low	Medium	Neo-classical contract, e.g. public procurement procedure
Distribution company with housing corporation	Heat supply to houses	Low	Low	Low	Classical contract
Housing corp-building contractor	Choice of appliances and construction and procedures	High	Low	Low	Bi lateral, neo-classical contract
Housing corp - Customers	Rental agreement (customer’s wishes) and billing	Low	Low	Low	Classical contract
Transportation company - customers	Billing	Low	Monthly	Low	Classical contract

Liberalization of the energy market
When determining the governance structures it is also important to consider the fitting of the governance system in a liberalized energy market. Customers in this market are free to choose their distributors individually, however in a heat network this is not possible, as houses in the same residential area are bound to a fixed supplier. There are several solutions to this problem, for example by using public procurement procedures every five years or by giving the residents a voice in the choice of the distributor.

Financial arrangements
Besides governance structures also the financing of the heat system and the tariffs for the heat are of importance to the institutional design. Delft Municipality is willing to invest in the heat system and has a total energy budget of approximately 10 million euros. They have already received an European subsidy of 2.9 million euros to help finance the pilot project of heating houses with waste heat.
Besides these sources of money Delft municipality is counting on housing corporations or building contractors to invest in the restructuring of the houses and to participate together with other private companies in a possible Public Private Partnership transportation company. This transportation company (relational contract) is one of the possible governance structures for the way the organization of the heat system is set up (see Table 2). If the transportation company is set up it should be economically viable and thus independent of Delft municipality in the long run. (see: Oosterwijk 2005)
An important objective of the municipality is making sure that the tariffs for the heat will not be higher than before. Therefore the arrangements for the determination of the tariffs for households connected to a city heating system will need to be reconsidered. Nowadays the tariffs are determined by EnergieNed, but the way these tariffs are calculated is unclear and there is no regular supervision by the law. (Gemeentelijk Platform Warmtetarieven, 2003)However Dte is working on a new tariff structure.

Nationally several arrangements have been setup to create incentives for sustainable development. The main incentives are Energie Investeringsaftrek and Energieprestatie advise (EPA). The most recent policy vision of the Ministry of Economic Affairs is set out in Innovation in Energy Policy (Ministry of Economic Affairs, 2004). By working together with the Rom-Rijnmond project there is a bigger chance for receiving these subsidies. These possible subsidies should be taken into account when designing the new system.

4.2.3 Actors and Games
Besides the institutional arrangements there are also some issues on the level of the individual actors and their games that need to be (re)designed.

In the first place the allocation of certain property rights will play an important role in this system. Unclear property rights could lead to opportunistic and strategic behavior. When considering the source of sewage water, arrangements for the ownership structure (property right) of the heat contained in the sewage water need to be considered. At this moment it is still unclear who legally owns the (heat contained in the) sewage water. The HHR Delfland treats the wastewater and owns the main pipes to and from the wastewater plant, the wastewater itself however is warmed up by heat from the users. The property rights are even more complicated because the Delft municipality owns the sewage system in the city. Will the transportation company that provides the warmth to the suppliers have to pay for the warmth and if so, who will they have to pay? (see De Volkskrant , 23-12-2004) In the second place also the property rights for the CO_2 credits are important. The industry supplying the heat, the transportation and distribution companies will all contribute to less CO_2 emissions. The question is who will be able to trade the CO_2 emission rights and earn money? Defining the property rights of the CO_2 rights and the wastewater will thus be important in the institutional design for heat systems using wastewater.

In the Rotterdam case the transportation company is a new company formed by Public, Private Partnership. The formation of such a company in Delft will thus bring a new actor to the decision-making arena. One of the main advantages of creating a new company with different parties is that this will create more will and support among the participating companies.

4.3 Design space for the process design

The process design enables actors to explore the way the design will be made and to determine the rules of the game. Since the system that is to be designed is one that involves many different actors with different goals, it is wise to set up the rules for the design before starting the process. By doing so, conflicts during the process can be avoided. (De Bruijn et al., 2002)
Since in this case the system for city heating is going to be designed in an educational setting, a process design with involvement of all relevant actors is not possible. However, it is useful to consider and describe the progression of the process design as it would occur in reality.

A criterion for the success of a process lies in the sense of urgency that is present. The actors need to be convinced that there is a problem that needs to be solved and can only be solved by some form of cooperation. Another important condition for the success of a process design is that it should be attractive to each of the parties involved (De Bruijn et al., 2002). The actors should be convinced that the design offers them a chance of influencing the decision-making.
Phases that can be distinguished in the process design are problem exploration, actor scans, quick scan of configurations and determining the process dilemmas, fixing the rules of the game and fixing the agenda (see De Bruijn et al., 2002). The dilemmas are a result of different meetings between the participating actors. The rules of the game are also set by the participating actors and will have to be followed by all the players. These process rules will always result from some form of negotiation. The rules can concern information sharing, conflict handling and exit-rules.

As mentioned above, for making a complete process design, information about the relevant actors is necessary. In this stage of our research however, no decisive information can be given about the actors that will finally be involved in the decision-making process and will eventually cooperate for developing the city heating system. For now, it is not yet clear which company is going to be the heat supplier nor which housing association will be involved. The composition of the group of actors that will participate in the decision-making process will have fundamental consequences for the design of the process. This composition will depend on the choice for the alternative that is going to be designed in the second phase of our research. Since this choice will be made at the end of the first phase, a complete and detailed process design cannot be made at this moment. However, in order to provide some insight in the future process and to lay ground for the final process design, some relevant and already known issues will be discussed here.
First a stakeholder analysis will be provided. Although it is not yet known who will participate, it is useful to give an overview of the relevant actors and their interests.
Secondly, a scenario will be provided of a formed group of actors to create a brief insight in how a process design could look like. Secondly it will be made explicit what needs to be done in the second phase of our research, regarding the process design.
Finally, based on these analyses the major decisions that are to be taken will be summarized.

4.3.1 Stakeholder analysis

Which actors should be involved in the process and who will form the centre of the process? Which actors do have a high dependence for Delft municipality? And when will actors be convinced of participation? These kind of questions need to be answered in order to make a process design. One way of doing this is using the actor and network analysis. For this end, at first an inventory is made of all possible relevant actors, shown in Table 6 in Appendix 2. A brief description of each of these actors is given in Appendix 2

Which housing associations, heat suppliers, energy companies and developers have to participate will follow from the selected alternative. The housing associations in Delft include DelftWonen Vestia, DuWo and Vidomes. These housing associations are active throughout all districts in Delft. Thus, in each district, buildings are owned by several housing associations. Vestia differs from the other housing associations since they have their own project development unit. The possible heat suppliers include DSM Gist, Delfluent and the Botlek area.
The network operator will be responsible for operating and maintaining the regional distribution network of the city heating system. When implementing the city heating system, a new network will be constructed and the current gas network will not be used anymore in the restructured district. This new network has to be supervised by a network operator. The network operator can be different from the current network operator, Eneco, but will likely be an energy company as well. Whether the operator will be an integrated company (supply and supervising) depends on the institutional arrangements that are to be made. The question whether the network operator will supervise the electricity network and the city heating system network or only the city heating system network also depends on these institutional arrangements.
The energy companies that currently supply energy in Delft are Eneco, Essent, and other new companies that entered the market due to the liberalization.
The developers cannot be made explicit here, since the developer will be selected based on the chosen institutional arrangement (tendering etc.).
Secondly, to explore the core values, the actors' problem perceptions, interests and goals are analyzed, using the actor- and network (Enserink et al., 2002). By analyzing these issues, possible points of future cooperation or conflict can be discovered. These issues are presented in Table 7 in Appendix 2.
The fact that there are many actors involved with all different core values, almost undoubtedly leads to certain points of conflicts during the decision making process. In order to protect the core values during those conflicts, it is favorable to assess the resources of the actors and the possibilities for substitution of these actors. Assessing these issues will also provide information on the dependence of the problem owner of each of these actors, which again will provide insight in possible points of cooperation and conflict.

From Table 8 (Appendix 2) it can be concluded that the municipality of Delft, for the development and implementation of a city-heating system is dependent on a large variety of parties. From the actors presented, the following can be pointed out as critical and will have to form the centre of the decision making process (see also the representation in Figure 10 where they form *Level 1*):

- Housing associations that are active in the districts where the city heating system is to be implemented
- Developer
- Heat suppliers
- Distribution network operator

These actors will have to form the centre of the process and will be of great influence for the results of the process. Other actors, like the ministry, will be involved in the process by possible future provision of subsidies for example, but the involvement in the decision-making process will not be that intensive. In the figure below an overview is given of the different levels of involvement and dependence.

The dependence of the municipality of the critical actors is not only being influenced by their resources, but also by their willingness to use their resources. When an actor will be confronted with high costs or benefits, this actor will probably be dedicated. So, it is useful to assess the level of dedication. In Table 9 in Appendix 2, an overview of the actors with the same interests, perceptions and goals and the actors with opposite interests, perceptions and goals is given. This may give the municipality an impression of imaginable reactions from the different actors. From Table 9 it can be concluded that many actors are dedicated, which means that active participation can be expected. Therefore, a good process design is important.

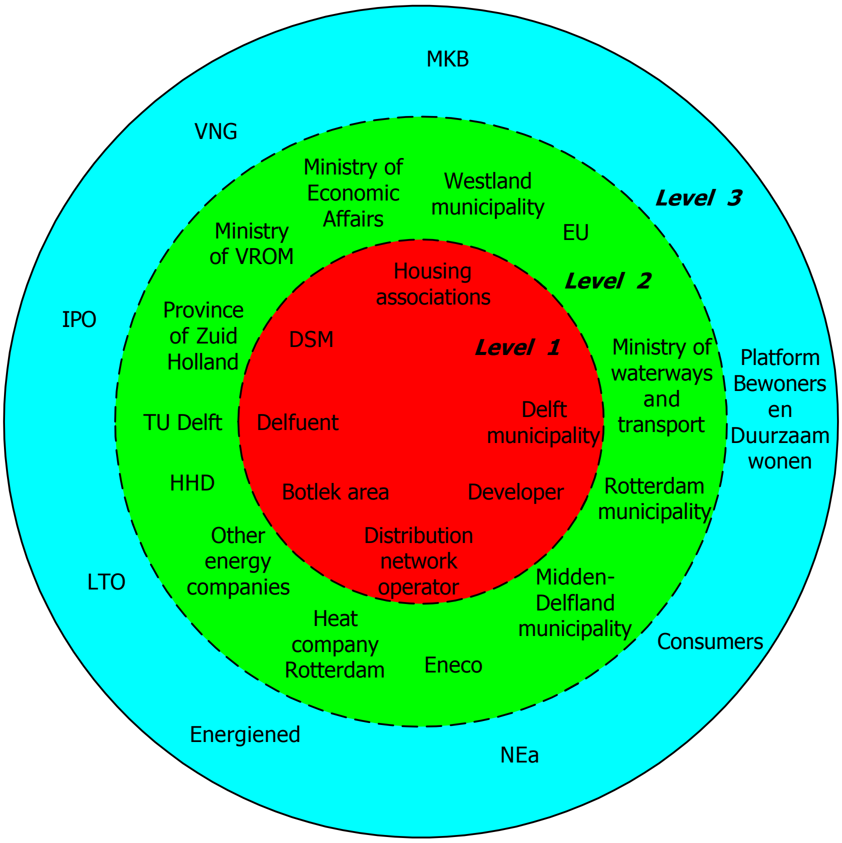

Figure 10. Three levels of actors

Level 1: The centre of the process: This level represents the critical actors; these actors need to be involved during the entire decision-making process. They are of great importance for the results of the decision-making process.

Level 2: The second layer of the process: This level represents the actors that do have certain decision-making power, but that will not be directly involved in the decision-making process. These actors may be asked for participation somewhere in the process.

Level 3: The third layer of the process: This level represents the actors that do not have decision-making power. These actors will probably not be involved in the decision-making process, but some of them do have certain interests in the project.

Now it is determined which actors will be critical for the process, it is useful for the municipality to find out how these actors can be convinced to participate in the process and to contribute to the city-heating project. The reasons for these actors to participate in the process can be partly derived from the opportunities of the project described in
Table 7 in Appendix 2 and from the goal trees from the critical actors (see Appendix 2). The perceived difficulties of participating and possible ways for the municipality to convince them are summarized below in Table 3.

Table 3. Perceived difficulties of actors and ways to convince to participate

Actor	Perceived difficulties	Ways to convince
Housing associations	Financial issues (additional costs leading to higher rents) Limitation of freedom of choice for supplier	Image improvement Being innovative Compensation with new working areas Improvement of the quality of the buildings
DSM	Decreasing flexibility Increase of costs (due to operational adjustments)	Achievement of CO_2 credits Financial rewards for delivered energy Image improvement
Delfluent	Decreasing flexibility Increase of costs (due to operational adjustments)	Financial rewards for delivered energy
Botlek area	Decreasing flexibility Increase of costs (due to operational adjustments)	Achievement of CO_2 credits Financial rewards for delivered energy Image improvement
Developer	Lack of technical knowledge	Cooperation with the participating energy company Image improvement
Distribution network operator	Additional costs without sufficient benefits	Vertical integration with supply Prospect on making profits

4.3.2 Actor group formation, scenario and experts

A written scenario of how an actor group could be formed and what the implications are for the process design can be found in Appendix 2. Dependent on the group formation, choices will be made on the experts that need to be consulted. The actors in the group formation should agree on the selection of these experts. Another consequence of the group formation is the level of command and control the municipality of Delft can use. It is likely that the municipality can use command and control in one group more effectively than in the other, also due to the chosen institutional arrangements. For instance, in a free market fewer possibilities for command and control are present.
It should be noted here that the formation of these groups could change during the process. Decisions that are made during the process may require some additional actors to participate in the process. For instance, when a decision is made that results in possibilities for the use of certain subsidies, the ministry of VROM can be asked to participate in the process. Therefore, the process should be designed such that the entry barriers for newcomers are low.

4.3.3 Process design in second phase

As was mentioned above, not enough information is available at this moment to make a complete and detailed process design. The information provided in this paragraph will be used as a basis for the final process design that will be made in the second phase.

The final process design, that is to be worked out in the second phase, must describe the decision-making process in a very detailed way. In this stage, only a few things can be said about the decision-making process.

At first, the decision-making process must be directed by a process manager. The actors that will form the centre of the process must agree upon the choice for this process manager and his tasks, since all parties have to be convinced that they are participating in a fair process.

Secondly, the decision-making process must consist of clear steps. These different steps must have their own deliverables, (e.g. contracts), rules, actors and roles and structure. In the process design these issues need to be specified for each step. The different steps in the process could, for instance, be the following:

- Problem definition
- Requirements analysis
- Design space analysis
- Decision
- Implementation
- Evaluation
- Maintenance

Thirdly, the process must have a certain time-path in order to guarantee the speed of the process. The critical actors must agree upon this time-path.

4.3.4 Conclusion

From these paragraphs the major decisions that are to be made during the process design can be derived.

- Selection of critical actors (e.g. which heat supplier, which energy company)
- Division of the CO_2 credits (since this functions as a very important way of compensation)
- Choice for a process manager
- Choice for the experts
- Construction of a time-path
- Choice of steps
- Deliverables for each step
- Exit- and entry moments and conditions

5 System requirements

In this chapter we have sorted the requirements according to theme. In Chapter 7 we will list all requirements (technical, institutional and process) according to functionality. The requirements within the themes and between the themes are interrelated. These interrelations will be discussed in paragraph 5.4. They are first discussed separately to give a good overview to the reader.

5.1 Requirements for the technical design

The requirements in this chapter are derived as follows. First we used the checklist of Bahill and Dean (1999) and some storyboards (see Appendix 3). We used brainstorming and the stakeholder analysis.

A requirement is that the system contributes to the overall sustainability of Delft. A requirement is that the energy used in our system must be currently unused energy. The utilization of this waste energy for city heating replaces (part of) the current demand for fossil fuels. This is only true if the source of energy is currently unused.

The main goal of Delft municipality can be described as: The energetic system of Delft has to become more sustainable (requirement 1) (see Delft Municipality, 2003). The first requirement therefore is: *the system must increase sustainability*.

This requirement of sustainability can be decomposed in the following requirements:

a) The system should at least in part use energy, which is currently unused.
b) The energy used should replace the current demand for fossil fuels partly.
c) The system's energy sinks must contain at least one form of city heating for Delft.
d) The system must perform with maximum energy efficiency.
e) The system must emit as few greenhouse gas emissions as possible.
f) The system should have minimal negative local, regional and global environmental impact.

Requirement a) can be explained as follows: if the energy used for city heating is currently unused, the design is inherently sustainable, because it uses energy that is otherwise dispersed in the environment. The utilization of this waste energy for city heating replaces (part of) the current demand for fossil fuels, because current sources for residential heating are fossil fuels (gas). This is only true if the source of energy is currently unused (waste).

Another requirement is: *the city heating should be in compliance with the user's needs* (requirement 2). To operationalize this requirement, goal trees and storyboards are used. (See appendices). This requirement can be decomposed in the following requirements:

a) The size of the energy system must be at least 5% of the yearly energy demand of Delft (while the goal of Delft is to achieve 15% of the energy demand in a sustainable way and this project must be of significance we assume 5% of the energy demand is a reasonable minimum).
b) The supply of energy should be flexible in the way that it is robust with respect to the daily, seasonal and long-term fluctuations in demand.
c) Because of b, the system should use more than one source in order to be robust
d) Because of b, a minimum reserve margin of 20% above current peak demand for expected and unexpected growth of demand must be implemented. Because heat autonomous demand has declined over the past years (see Energie in Nederland, 2005) and the system will be

designed for a selected amount of houses, an increase in peak demand is not expected. Therefore, we assume that a reserve margin of 20% of current peak demand is sufficient.

e) The system should have a reliability of at least 99,5% (general assumed figure, which equals a maximum of 44 hours of non delivery per year)
f) The system should have maximum reliability
g) The system must deliver heat at the correct temperature, depending on the technical solution. For hot tap water, this temperature should be at least 66.5 ^{o}C. For low temperature heating, this should be 55^{o} C and for radiator heating, this should be 90 ^{o}C (Novem, 2002).

The system has to be technically and economically and legally feasible (requirement 3). This requirement can be decomposed in the following requirements:

a) The system must be safe enough to at least meet the law for individual risks and the norm for group risks (see Ministry of VROM, 2005 for details on how this should be done in practice).
b) The systems lifetime must be secured for a minimum of 35 years (35 years is used as technical lifetime for heat system for glass houses by Kempkes and de Zwart (2002)).
c) There needs to be an arrangement to secure heat delivery after the systems lifetime expiration.
d) The system should have the highest profitability possible to lower the costs for citizens.
e) The energy costs increase for citizens who use the system must be below 15% (15% seems reasonably defendable in achieving support by customers).
f) The system should use as much as possible potential financial incentives of governmental organizations that support the development of sustainable energy systems.
g) The system must contain at least one energy source (this requirement is however redundant because of requirement 2c).
h) The system must contain at least one energy sink.
i) The system must fit to current households equipment with minimal additional costs (fixed, applications, maintenance), hinder and downtime.

5.2 Requirements for the institutional design

The requirements for the institutional design are derived from the institutional analysis (see Appendix 4) and the description of the design space (see paragraph 4.2). Because the requirements for the institutional design cannot be seen apart from the technical and process design some contradictions and overlapping may occur. These will be dealt with later on in the paragraph on trade off's (paragraph 5.4).

Based on layer one and two, representing the institutional environment in the model of Williamson (1998) the following requirements can be derived.

The design has to match with the institutional environment (requirement 4):

a) contribute to the reduction of green house gasses, thereby following the regional, national, European and global laws, directives and protocols, as described in Appendix 4;
b) be in accordance with the existing values and norms in our society, as described in Appendix 4;
c) be in accordance with all national, European and global laws;
d) be in accordance with the goals and expectations written down in the Delft municipal 3E plan which in total reduce the CO_2 emission reduction with 33500 ton per year in 2012.
e) take into account that trust and competence building are important (Original Institutional Economics);

Based on layer three from the model of Williamson (see Appendix 4) the following requirements can be derived:

The design has coordinate transactions efficiently (requirement 5):
a) include governance structures to coordinate the interactions between actors in the most efficient way (keeping in mind Transaction Costs Economics);
b) take into account the possible subsidies available to support the costs of implementing such a design;
c) reconsider the way the tariffs are set up;
d) make sure that the design fits with the liberalized energy market;

Based on level four the following requirements are important:

The design has to deal with appropriate definitions of actors and games (requirement 6):
a) deal with problems arising from unclear sewage water and CO_2-credit property rights;
b) use the advantages of PPP to create a base for support among stakeholders;

5.3 Requirements for the process design

The decision-making process should fulfil certain requirements in order to let the process be a success. These requirements should be taken into account by designing the process.

According to De Bruijn et al. (2002), a process has to fulfil four core elements. During all the steps the process will consist off, openness, protecting the core values, speed and substance should be guaranteed. Openness implies that all the decision-making processes are open; all the relevant actors should be involved, substantive choices should be transformed into process agreements and the process should be transparent. Furthermore, during the process the core values of the actors need to be protected, in order to keep the process attractive for parties, their key interests should be safeguarded and the process should offer the participants an exit option. It is also important to guarantee incentives for speed in the process. In order to guarantee the speed of the process, the process should for instance create prospects of gain and incentives for cooperative behaviour. Finally, the process needs to offer possibilities for a substantive quality of the results.
Based on these four core elements and on the analysis worked out in the design space, some more specified requirements can be discussed here. Although these requirements give some insight, it should be noticed that they are still preliminary, and dependent on the selected alternative this list of requirements will be replenished.

5.3.1 Requirements

Critical actors must participate during the whole decision-making process (requirement 7).

The process should have low entry and exit barriers (requirement 8).
The core values of a future network operator, the housing association, the heat supplier and the developer must be protected (requirement 9):
a) Improvement and maintenance of construction and technical quality and/or the lettability of the buildings for the housing association
b) Continuity and making profits for a future network operator
c) Continuity and making profits for the heat supplier
d) Continuity and making profits for the developers

At the beginning of the process a process manager must be selected (requirement 10). The choice for this process manager must be based on consensus within the group of critical actors.

Depending on the group of critical actors, experts must be consulted in order to guarantee the substance of the process; the actors must agree upon the choice for these experts (requirement 11).

The process must consist of different steps: the process design must explicit the deliverables, actors and roles, rules and structure of each step (requirement 12).

5.4 Trade-offs between requirements

Some of the requirements presented above are conflicting. During the development of the city heating system, these trade-offs should be made. The trade-offs can be divided in four levels. The first level consists of the trade-offs between one single requirement and (almost) all other requirements of the system. The second level describes the conflicts between the requirements of the three domains (technical, institutional and process). The third level entails the conflicting requirements within one domain. The last level describes the conflicts within one type of requirement. In Figure 11 these levels are presented and some examples of trade-offs are given.

level		representation			examples
1.	requirement versus system	system			costs versus other system requirements freedom of choice of end user versus other system requirements
2.	between domains	P	I	T	number of sources versus process progress efficiency of transaction versus system acceptability
3.	within domain	P	I	T	operational flexibility heat suppliers versus achieved CO_2 credits average temperature delivered heat versus efficiency safety of the system versus investment costs efficiency versus robustness progress versus ease of entry and exit substance versus protection of core values
4.	within subject				investment costs versus maintenance costs

Figure 11. Levels of trade offs

5.5 Performance indicators

From the presented requirements in the preceding paragraphs, a list of performance indicators can be derived. These performance indicators will be used to test the performance of the city heating system on the requirements. This list can be found in Appendix 5.

6 Choice design alternative

In order to further develop the heat system a quick scan of possible design alternatives is made on a very generic level. For this quick scan five generic design alternatives are screened on the four general requirements of Chapter 3, namely robustness, total costs, compliance to interests of critical actors and contribution to reduction of CO_2 emissions.
The alternatives are:

1. A system that combines as many sinks as possible (residential areas) with as many sources as possible;
2. A system that combines as many sources as possible with one sink;
3. A system that combines one source with as many sinks as possible;
4. A combination of one sink and one source;
5. Do nothing, which means that the residential areas will not be connected to a heat network at all.

These alternatives are chosen to focus the design, without loosing too many degrees of freedom. The results are represented in Table 4. Argumentation for the scores is described in Appendix 6.

Table 4 Scorecard for the basis of design

		criteria			
		robustness	total benefits – total costs	compliance to interests of critical actors	contribution to reduction of CO_2 emissions
alternatives	1. many sources, many sinks	++	+	+	++
	2. many sources, one sink	++	– –	–	0
	3. one source, many sinks	–	+	–	+
	4. one source, one sink	– –	+	– –	0
	5. do nothing	0	0	0	– –

(green)	++	(light green)	+	(yellow)	0	(orange)	–	(red)	– –

According to the above criteria, the best alternative to further develop is the combination of as many sources as possible with as many sinks as possible. In this case this means that DSM, Delfluent and Botlek will contribute heat to the heat network and at least seven residential areas and maybe even more sinks will use this heat for tap water and heating. It is important in this alternative to consider real options, such that even more still undiscovered or new sources and sinks can be added to the network.

7 Conclusions

Delft has outlined its policy for increasing efficiency of energy use in its 3E climate plan (Delft Municipality, 2003). The Trias Energetica concept (Ecofys, 2005) defines three ways to achieve this goal: maximize the use of sustainable energy sources, use non-renewable energy sources efficiently and/or minimize energy use. Delft considers a solution to increase the efficiency of the use of non-renewable energy: the use of (industrial) waste heat for city heating. Delft municipality, the problem owner of this design project, is exploring the possibilities for this type of systems. Based on a problem analysis, we have defined the design problem as follows:
Which energy system can the municipality of Delft best apply for city heating with waste heat, taking into account the interests of Delft and of the stakeholders that Delft is critically dependent of, i.e. the heat suppliers, the housing corporations and the future network operator?

The deliverable of this report is a basis of design. A basis of design is an overview of performance indicators at system level, the design space and the goals and constraints the design will have to meet. This basis of design will guide us in the second phase of this project, i.e. the actual design of a city heating system.

In this report, we wanted to diverge as much as possible in order to browse the design space. However, in order to demarcate our basis of design, we already have made a few choices that will determine the remainder of the design project. In the next paragraph, we will describe the choices we have already made. Also, we describe the major design decisions that will have to be made in the second phase of this project, i.e. the design of the city heating system according to this basis of design.

7.1 Design decisions

7.1.1 Design decisions made

In Figure 1 in Chapter 1 we demarcated this project geographically and in time. Geographically we demarcate our research to the region of Delft. The time demarcation is 40 years. First there is a development and implementation time of 5 years (until 2010) and then the system lifetime of 35 years (until 2045).

Institutional:
The institutional environment of the system, i.e. the informal and formal rules, are not considered design variables. The choice of governance structures has not been made because it will not only depend on the efficiency of the system but also on other system requirements. For this choice, the solutions chosen for the city heating system in Rom-Rijnmond will serve as an example.

Process:
A few actors are considered critical and will need to form the centre of the decision making process: housing associations that are active in the districts where the city heating system is to be implemented, housing developers, heat suppliers and distribution network operator.
Other decisions could be made because the process design depends on the choice of the combination of sources and sinks chosen.

Technical:
Based on the four criteria that are essential to all critical stakeholders (robustness, total benefits – total costs, compliance to interests of critical actors, contribution to reduction of CO_2 emissions),

we have chosen the design alternative: Include as many sources and sinks as possible in the design (at least DSM, Delfluent, Botlek, seven residential areas in Delft). We have chosen to focus only on a city heating for Delft. Other possibilities, such as applying heat in greenhouses and using aquifers for storage are not considered yet.

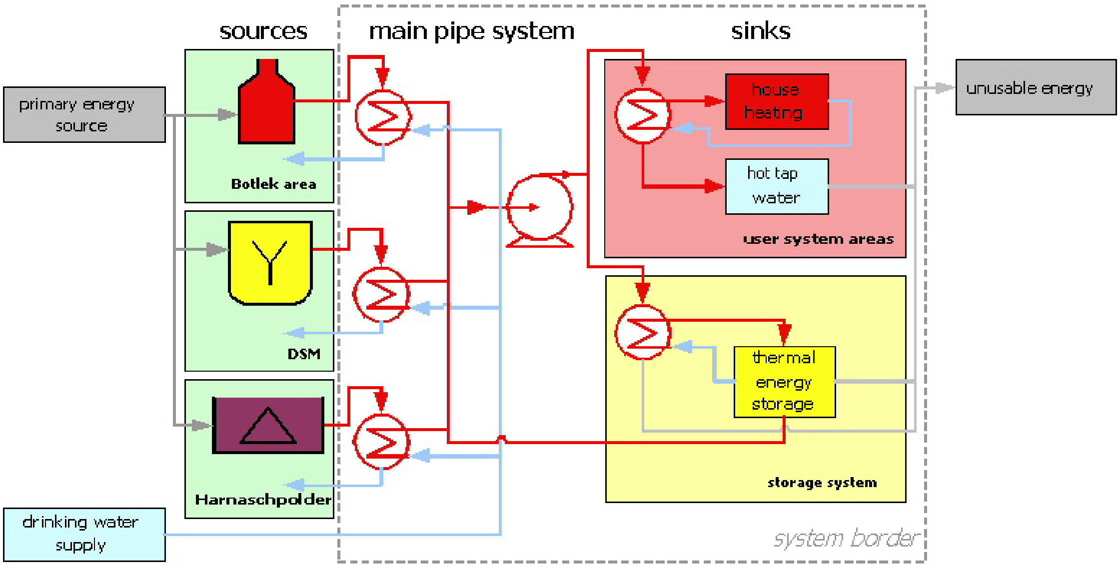

Figure 12. Preliminary rough design

7.1.2 Design choices to be made

For the convergent phase, some design decisions have to be made. A general design choice concerns the trade offs. Decisions have to be made about how to deal with the trade offs, described in Chapter 5.
Regarding the institutional design choices are to be made about the governance structures that have to be applied for the different transactions. The most important choice here is how to organize the relation between the transportation company and the distribution company. Another choice to be made concerns the definition of property rights of CO_2 and sewage water.
The major decisions that are to be made during the process design are the selection of critical actors (e.g. which heat supplier, which energy company), the division of the CO_2 credits (since this functions as a very important way of compensation), the choice for a process manager, the choice for the experts, the construction of a time-path, the choice of steps, the deliverables for each step and the exit- and entry moments and conditions
Technical design choices can be found in the suitable placement of pumps, heat pumps and heat exchangers (e.g. pinch technology), in the placement of pipelines. Another choice regarding the technical design concerns the flexibility of the system; choices are to be made on the inclusion of real options to change the sources and sinks connected to the system, storage capacity, and keeping sources stand-by as reserve capacity.

7.2 Reflection

In order to provide some learning effects we evaluated the decisions that where made in this first part of our design project.
It should be noted that the choice for the alternative might cause some resistance among the different stakeholders, since this choice is made without complete knowledge of the process requirements. This is due to the fact that this project is conducted in an academic setting, instead of in a multi-actor setting, as would be the case in real life.
The choice for the alternative with all the sources and sinks inherently involves many stakeholders, which may harm the progression of the decision making process.
One last remark concerns the educational setting this project is made in. In case a real process design where followed this could possibly have led to a different choice.

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9 Appendices

Appendix 1: Working arrangements

Our working arrangements consist of the following. For this first part of the project, we have assigned a chairman (W. Oosterwijk) and a secretary (E. Chappin). For the second part of the project, the role assignment will change.
We are committed to making at least one appointment with each supervisor, per part of the project. Important dates and deadlines are represented in Table 5.

Table 5. Planning of first phase.

Work -week	Date; time; loc.	Activity
1	10/2 TBM-B	Project kick-off
2		Project group meeting Browse design space and context of project
3	21/2 24/2	Project group meeting Meeting with Michiel Houwing (technical design) Make setup for report, start listing requirements and elaborating design space, describe use of methods / models / systems thinking
4	28/2	Project group meeting Meeting with Peter Jacobs (systems engineering) Continue / finish requirements and description of design space
5	7/3	Project group meeting Meeting with Peter Rommens (Delft Municipality) Finish requirements and description of design space
6	14/3 14/3 14/3 14/3 – 19/3	Meeting with Michiel Houwing (technical design) Meeting with Joop Koppenjan (process design) Meeting with John Groenewegen (institutional design) Implement recommendations from supervisors, continue reporting
7		Finish Basis of Design Continue implementing recommendations from supervisors Create sketches
8	31/3, 10:45-12:30; TBM-F	Halfway presentation and report

In order to manage the progress made in the project, we maintain a project archive. We store our written contributions, literature, meeting minutes, contacts etc. on a group directory. The secretary keeps the archive orderly.

Appendix 2: Stakeholder analysis

First a quick-scan is performed to identify all potential stakeholders (Table 6). The relevance of some of the stakeholders depends on the decisions made during the design process. Next the perceptions, interests and goals are analyzed (see Table 7). The criticality of actors analyzed (Table 8). After this, the dedication of actors is analyzed (Table 9). Goals and means of the different critical actors are studied and goal trees are listed after that. Finally, a scenario of a possible actor group formation is presented.

Table 6. Quick scan of actors

Actor	Short description
Public actors:	**EU:** The European Union (EU) sets out the main policy goals for its member states and sets many (environmental) constraints on the design space by their directives. **Ministry of Housing, Spatial Planning and Environment (VROM in Dutch)**: This ministry sets out goals and policy for the environmental and spatial planning aspects. **Ministry of Economic Affairs (EZ in Dutch):** This ministry sets out goals and policy for relevant subsidies and CO_2 emission trading. **Ministry of Waterways and Traffic (V&W in Dutch)**: This ministry sets out goals and policy for all water related aspects. **NEa**: The Dutch Emission authority (NEa) which will become independent of VROM in the future, deals with control and design of the emission trading system. **Province of Zuid-Holland:** The province of Zuid-Holland sets out regional policy and deals with inter-municipal aspects. **Delft Municipality:** Delft municipality is the problem owner and searches for possibilities for more sustainable energy use. **Hoogheemraadschap Delfland (HHD):** The body of surveyors of dikes for the region of Delfland (HHD) is in control of all waterways in the larger region of Delft. It deals with wastewater removal and drinking water supply. **Rotterdam municipality:** Since the Botlek area is situated in Rotterdam, Rotterdam municipality plays a role. **Midden Delfland municipality:** Since the AWZI Harnaschpolder is situated in Midden Delfland, this municipality plays a role. **Westland municipality:** Westland municipality will play a role in the process if greenhouses are selected as a sink. **Warmtebedrijf Rotterdam:** The heat company of Rotterdam is a cooperation (PPP) between Rotterdam municipality, port industry and distribution companies (e.g. Eneco), with the optimal use of waste water for city heating as their main goal. **TU Delft:** The technical university of Delft possesses a CHP, which could function as an emergency supplier.
Private actors:	**DSM Gist:** DSM Gist's Delft site consists of three plants: bakery ingredients, antibiotics and food specialties. DSM has expressed willingness to discuss allowing its waste water to be used for city heating. However, they have not made any definitive decision whether or not to participate in the project. **Delfluent:** The sewage treatment facility Harnaschpolder is a possible source of thermal energy where heat from industrial effluent streams can be used. Delfluent is a PPP from Vivende water (F), Rabobank, Europort, Delta

	Nutsbedrijven, Strukton en Heijmans. **Botlek area:** The Botlek hosts a wide number of oil refineries and the chemical companies and can function as a deliverer of heat. **Housing associations:** The housing associations active in Delft include Vestia, DelftWonen, DuWo and Vidomes. These housing associations are active in all districts of Delft. **Project developers:** The project developers may join a tender procedure to restructure a residential area. **Distribution network operator:** The network operator is responsible for maintaining the regional distribution network. When implementing the new system, a new network operator may be selected. Likely, this will be an energy company, which also has a private task in supplying energy and setting tariffs. **Eneco:** Eneco is the current distribution network operator and also delivers energy. **Other energy companies:** Since the network operator not necessarily will be the energy supplier, other energy companies may play a role when the system is implemented.
Interest groups:	**IPO:** The inter provincial consultation (IPO) is a cooperation between the twelve provinces of Holland which looks after the interests of these provinces **VNG:** Municipalities are united in the Vereniging van Nederlandse Gemeenten (VNG). VNG looks after the interests of municipalities and supports Improvement and maintenance of the power and quality of the local authorities. **MKB:** The Association of Dutch middle and small business (MKB) promotes the interests of the Dutch middle and small business. **Platform Bewoners en Duurzaam Bouwen**: Civilians are united in the Platform Bewoners en Duurzaam Bouwen to defend their values with respect to the sustainable development of houses. **EnergieNed:** EnergieNed is the branche organization that looks after the energy companies' interests and sets tariffs for heat supply. **LTO:** LTO Nederland is the Dutch Organisation for Agriculture and Horticulture (Land- en Tuinbouw Organisatie Nederland) in the Netherlands. LTO can play a role when it is decided to use the greenhouses as a sink.

Table 7. Analysis of perceptions, interests and goals.

	Problem perception				**Interests**	**Goals**
Actor	*Norm*	*Core of the problems*	*Opportunities*	*Influential instruments*		
Public actors						
EU	No deterioration of welfare in the EU	Creation of city-heating system based on waste heat, contributing to cleaner environment, but that has to fulfill directives	Possibilities for implementing this system in other EU countries when it turns out to be a success	Decision-making authorities Regulation and Rules Subsidies	Maximum welfare in the EU	A sustainable and efficient city heating system, fulfilling the EU Directives
Min VROM	No deterioration of living environment	Restructuring process of districts, with the use of waste heat	Possible improvement of the living environment	Decision-making authorities Regulation and Rules Subsidies	Maintenance of cities, a vital countryside, sustainable development of society, healthy and safe living environment, sustainable consumption en freedom to choose.	A city-heating system that contributes to a better living environment
Min EZ	No deterioration of economic position	The creation of a city-heating system with waste heat from industry water, that probably needs subsidies from the government	Possible improvement of the lettability of certain districts, improving the position of the housing corporations	Decision-making authorities Regulation and Rules Subsidies	Market in which entrepreneurs can prosper, in which there are equal chances, in which consumers have optimal freedom to choose and in which public interests are safeguarded.	An energy system which is economically efficient
Min V&W	No deterioration of the Dutch waterways and	The creation of a city-heating system with the use of waste heat		Decision-making	Protecting the Netherlands against the negative influences of water and	A city-heating system based on industry water, that

	highways	from industry water		authorities Regulation and Rules	providing it with safe, world-class connections (www.venw.nl)	efficiently uses this water
NEa (part of VROM until 2006)	Reduction of greenhouse gas emissions in The Netherlands	The creation of a city heating system which will probably emit less CO_2 and NO_x than the conventional system	Possibilities for implementing this system in other municipalities when it turns out to be a success	Supervision (monitoring, sanctioning)	Compliance of the Dutch firms to the rules and regulations for trade in NO_x and CO_2 emission rights	A sustainable and efficient city heating system, fulfilling part of the reduction targets
Province Zuid Holland	No deterioration of the position of Zuid Holland	Efficient use of waste heat from industry and other sources in Zuid Holland for city-heating	Possibilities for implementing the same system in other municipalities when this system turns out to be a success	Decision-making authorities Regulation and Rules	Maximum welfare in the province of Zuid Holland	A sustainable and efficient city heating system that creates satisfaction for stakeholders
Delft municipality	A sustainable city: a city that gives a central position to the future value of the city, that handles space, resources and energy in a sensible way, a city that unequivocally chooses for sustainable urban development (Delft municipality, 2004)	Creation of a city heating system that has to fulfil the requirements of sustainability and has to satisfy the inhabitants	Possibilities for implementing the same system in other districts when this system turns out to be a success Improvement of the municipality's reputation as a sustainable city	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Delft	A sustainable and efficient city heating system that creates satisfaction for inhabitants
Rotterdam municipality	No deterioration of economic position of Rotterdam	Creation of a city heating system in Delft with the use of heat from Botlek	Possibilities for implementing the same system in Rotterdam when	Decision-making authorities Regulation	Maximum welfare of Rotterdam	Optimize economic activity Botlek area

			this system turns out to be a success More income from taxes	and Rules License allotment Subsidies Participation / Agreement		
Midden Delfland municipality	No deterioration of economic position of Midden Delfland	Creation of a city heating system for Delft with the use of heat from the AWZI Harnaschpolder	Possibilities for implementing the same system in Westland when this system turns out to be a success More income from taxes	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Midden Delfland	Optimize the economic position of AWZI Harnaschpolder
Westland municipality	No deterioration of economic position of Westland	Creation of a city heating system for Delft with the use of waste heat. This system may possibly also supply the greenhouses.	Possibilities for supplying the greenhouses in Midden Delfland with the city heating system	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Westland	Optimize the economic position of Midden Delfland greenhouses
HHD	No deterioration of quality	The creation of a city-heating system with	Improvement in efficiency of the	License	Improvement and maintenance of the water	Efficient and maintaining use of

(Body of surveyors of dikes of Delfland)	of Delfland waters	the use of waste heat	use of waste water Improvement of the reputation of HHD	allotment	barrage, water management and water quality in Delfland (www.hhdelfland.nl)	Delfland waters
Heat company Rotterdam	No deterioration of operational flexibility No deterioration of profits	The creation of a city-heating system with the use of waste heat	Possible cooperation with a future heat company in Delft	Market knowledge Technical knowledge	Optimal use of waste water from companies in the Rotterdam port area, waste processing industries and power plants for the use of city heating	Making profits form possible future cooperation
TU Delft	No deterioration of TU Delft education and research	The creation of a city-heating system with the use of waste heat, where the CHP of the TU Delft can be used as an emergency supplier	More income by functioning as an emergency supplier	Technical knowledge	Optimal quality of education and research	Making profits from functioning as an emergency supplier

Private actors						
Distribution network operator	Limited additional costs from maintaining the network	Creation of a city-heating system with the use of waste heat and the need for technical restructuring Possibility of income loss due to higher energy efficiency	Gaining experience with the construction the new system, thereby improving their competitive advantage Enlarging market power on energy generation market	Market knowledge Technical knowledge Blocking power	Continuity	Making profits from the implementation of the new system

Eneco	No decrease of profits	Creation of a city-heating system with the use of waste heat, where the current gas network will become useless in the restructured area. The new system requires a network operator. This network operator may be different from the current.	Vertical integration	Market knowledge Technical knowledge Blocking power	Continuity	Remain the network operator, from the electricity network as well as the new network
Other energy companies	No reduction of profits (no income loss caused by higher energy efficiency)	Creation of a city-heating system with the use of waste heat and the need for technical restructuring Possibility of income loss due to higher energy efficiency	Gaining experience with the construction the new system, thereby improving their competitive advantage Enlarging market share	Market knowledge Technical knowledge Blocking power	Continuity	Making profits from the implementation of the new system
Project Developers	No reduction of profits	Creation of a city-heating system in restructuring projects, with the use of different technologies than usual	Gaining experience with the construction of buildings with the new system, thereby improving their competitive advantage	Blocking power Market knowledge Technical knowledge	Continuity, profit	Obtaining an attractive contract for building a city heating system
Housing corporations	Increase of lettability of the buildings that are to be restructured	The creation of a city-heating system in districts that are to be restructured	Improvement of the lettability of the buildings	Ownership rights Blocking power	Improvement and maintenance of construction and technical quality and/or the lettability of the buildings (see Waals, et al., 2000)	Energy savings and comfort improvement in restructuring projects in order to fulfil the construction, technical and architectural quality (see Waals, et al., 2000)

DSM	No reduction of profits, no increase of costs	Waste heat of DSM has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Market knowledge Technical knowledge	Continuity, profits	Making profit out of a city-heating system Achieving CO_2 credits in order to expand activities No distortion of the operational flexibility
Delfluent	No reduction of profits, no increase of costs No additional costs for breach of contract	Waste heat of the AWZI has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Technical knowledge	Continuity, profits	Making profit out of a city-heating system No distortion of the operational flexibility
Botlek area	No reduction of profits, no increase of costs	Waste heat of the Botlek has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Market knowledge Technical knowledge	Continuity, profits	Making profit out of a city-heating system Achieving CO_2 credits in order to admit new companies to Botlek area No distortion of the operational flexibility

Interest groups						
MKB (Association of Dutch middle and small business)	No deterioration of the position of the entrepreneurs	Creation of a city-heating system with the use of waste heat from industrial firms	Image improvement of the Dutch middle and small business	Advising	An entrepreneur-friendly environment in The Netherlands	Development of a city-heating system to the satisfaction of participating Dutch middle and small business
IPO (Inter provincial consultation)	No deterioration of working conditions of provinces and sustained cooperation between provinces	Creation of a city-heating system	Possibilities for cooperation and learning between provinces when the city-heating system will be implemented in other provinces as well	Advising	Optimise working conditions of provinces and stimulation of provincial restructuring processes (www.ipo.nl)	Development of a city heating system
VNG (Association of Dutch municipalities)	No deterioration of the power and quality of local authorities, enough participation of local authorities in decision making process	Creation of a city-heating system within a municipality, upon initiative of the municipality	Possibilities for implementing the same system in other municipalities when this system turns out to be a success Example setting by Delft municipality	Advising (pro-active and on request) during consultations with government, provinces and HHD	Improvement and maintenance of the power and quality of the local authorities	Development of a city-heating system with enough involvement of the local authorities
Platform Bewoners en Duurzaam Bouwen	Increase of number of houses built with sustainability in mind	Creation of a city-heating system with the use of waste heat	Improvement of the sustainability of the construction of buildings and living	Advising	Sustainable construction and living	City heating system implemented in the most sustainable way
LTO	No deterioration of the position agricultural and	Creation of a city-heating system in Delft, which	Possibilities for achieving CO_2 credits when the greenhouses	Advising	A strong economic and social position for farmers, and a	Achieving CO_2 credits when greenhouses are

	horticultural industry.	possibly also will function as heat supplier for the green houses in Westland	are added to the city heating system		sustainable agricultural and horticultural industry in The Netherlands (www.lto.nl)	added to the city heating system
Energiened	No deterioration of the functioning of the energy sector	Creation of a city-heating system with the use of waste heat and the need for technical restructuring	Improvement of image of energy companies	Market knowledge Advising	Creation of a liberalized balanced energy market that functions effectively, a healthy, socially acceptable energy sector, operating in fruitful business climate. (see Energiened)	Implementation of an energy system that contributes to a healthy energy sector
Consumers	No deterioration living environment No increase in costs Reliability of heat supply	Creation of city-heating system which demands adjustments of current systems and takes time	Improvement of the living environment	Blocking power	A highly qualitative and reasonably priced house Maximum reliability of heat supply	Improvement of the comfort and quality of the houses Minimal hinder during implementation Minimal cost increase (energy costs, switching costs, rent increase and additional costs) Maximum reliability of heat supply

In this diagram, the ‘causes’, as described in the original diagram of Enserink et. al. (2002) are replaced by ‘opportunities’, since the case of city heating actually describes a solution looking for a problem and the suitable moment to implement. The influential instruments named in this table are explained in more detail in the paragraph of institutional design.

Table 8. Criticality of actors.

Public Actors	Resources	Possibilities for substitution	Dependence	Critical actor?
EU	Rules and regulation Decision making authorities Subsidies, Taxes	No	Medium	No
Min VROM	Rules and regulation Decision making authorities Subsidies	No	Medium	No
Min EZ	Rules and regulation Decision making authorities Subsidies	No	Medium	No
Min V&W	Rules and regulation Decision making authorities Subsidies	No	Medium	No
NEa	Sanctioning	No	Small	No
Province Zuid Holland	Rules and regulation Decision making authorities	No	Medium	No
HHD	License allotment	No	Medium	No
Rotterdam municipality	Rules and regulation Decision making authorities	No	Medium	No
Westland municipality	Rules and regulation Decision making authorities	No	Little	No
Midden Delfland municipality	Rules and regulation Decision making authorities	No	Medium	No
Heat company	Market knowledge	No	Little	No

Rotterdam	Technical knowledge			
TU Delft	Technical knowledge CHP	No	Medium	No

Private Actors	**Resources**	**Possibilities for substitution**	**Dependence**	**Critical actor?**
DSM	Market knowledge, Technical knowledge	Yes	Medium	Yes
Delfluent	Technical knowledge	No	Medium	Yes
Botlek area	Market knowledge, Technical knowledge	No	Medium	Yes
Developers	Market knowledge, Technical knowledge	Yes	Large	Yes
Housing associations	Ownership rights	No	Large	Yes
Distribution network operator	Market knowledge, Technical knowledge	No	Large	Yes
Eneco	Market knowledge, Technical knowledge	Yes	Medium	No
Other energy companies	Market knowledge, Technical knowledge	Yes	Medium	No

Interest Groups	Resources	Possibilities for substitution	Dependence	Critical actor?
Platform Bewoners en Duurzaam Bouwen	Advising	Yes	Little	No
IPO	Advising	Yes	Little	No
VNG	Advising	Yes	Little	No
MKB	Advising	Yes	Little	No
Renters	Blocking power	Yes	Little	No
Energiened	Market knowledge, Advising	Yes	Little	No
LTO	Advising	Yes	Little	No

Some of the dependencies and substitutabilities are obvious; a couple of them will need some explanation. First, DSM is considered to be substitutable, since in theory, another firm could do the tasks of DSM. The AWZI Harnaschpolder and the Botlek area are considered not be substitutable. However, obviously all the three heat suppliers have a high dependence since they have to deliver the waste heat. For the developers, it is said in the diagram that they are substitutable, since more than one developer will be available to develop the project. The developers have a high dependence though, since they are partly responsible for the construction of the buildings with the new city-heating system.

The housing corporations are considered not to be substitutable. They are all active in all the districts of Delft, thus when restructuring one district all the housing associations active in that district should agree. At the same time, these housing corporations have a high dependence. The housing corporations are the owners of the buildings and the parcels they are built on. The ownership rights give them great influence.

Eneco is the current network operator. In the above table, it is described as a non-critical actor. When implementing the new system, a new network will be constructed which needs to be supervised. This can be done may another company than Eneco, depending on the institutional arrangements. When another company will be network operator, Eneco looses his function as supervisor of the gas network and possibly also of the electricity network. When this will occur, Eneco needs to be compensated for the losses in profit they will face.

Table 9. Dedication of actors.

	Dedicated actors		Non-dedicated actors	
	critical	**non-critical**	**critical**	**non-critical**
Aligned perceptions, interests and goals	Distribution network operator, Developers, Vestia, DelftWonen, DuWo, Vidomes, Project developer	Platform Bewoners en Duurzaam Bouwen, IPO, VNG, EU, Ministry EZ, Ministry of V&W, Ministry of VROM, NEa, Province of Zuid Holland, HHD, Energiened, TU Delft		Rotterdam Municipality, Westland Municipality, Midden Delfland municipality,
Conflicting perceptions, interests and goals	DSM Gist, Botlek, Delfluent	MKB, LTO, Eneco		Consumers

Above table shows the dedication of the relevant actors and whether their interests, perceptions and goals are aligned with the municipality. Since it was found out that housing associations highly focus on energy savings, it is considered here that they are aligned with the municipality. The heat suppliers are considered to have conflicting perceptions, interests and goals. They highly focus on achieving profits, especially DSM and the Botlek area and the introduction of a city heating system may be perceived as decreasing the flexibility of the operations. Furthermore, the table shows that the consumers' perceptions, goals and interests are conflicting with that of the municipality. The consumers probably will perceive the implementation of a city heating system as a limitation of their freedom to choose their supplier. Moreover, they will be skeptical because of possible increasing price.

Objective analysis of Delft municipality and critical actors

The following pages contain goal trees and means end analysis. These are the result of objective analyses of Delft municipality and critical actors.

Our point of departure is what Delft municipality stated as being its overall goal: sustainable development (economically, ecologically and socially) of Delft (Delft municipality, 1999). In the goal tree (Figure 13) we decompose this high-level goal, to show when Delft will consider the goal to be met. In fact, we operationalize Delft's overall goal. Second, we want to identify how Delft municipality can achieve its overall goal. We do this with a means-ends diagram (Figure 14). Both diagrams are based on information as stated in Delft's 3D plan (Delft municipality, 1999) and Delft's 3E plan (Delft municipality, 2003).
We will perform the same analyses to specify the objectives and means of the critical stakeholders. The information that is used in the objective analysis of Eneco Energie has been found on their corporate website (Eneco Energie, 2005). The information used in the analyses of the objectives of the housing corporations is derived from the websites of the three housing corporations of Delft: Stichting Duwo (2005), Delftwonen (Woonbron, 2005), Vidomes (2005) and Vestia (2005). We have generalized this information such that the diagrams are applicable to any housing corporation. The reason that we do this is that we have not decided upon one specific district or housing corporation in this stage of the project. The information that is used in the objective analysis of the heat suppliers has been concluded based on the interview with a

representative of Delft municipality, who has been in contact with these potential suppliers in order to assess their willingness to contribute to the city heating system (Oosterwijk, 2005).

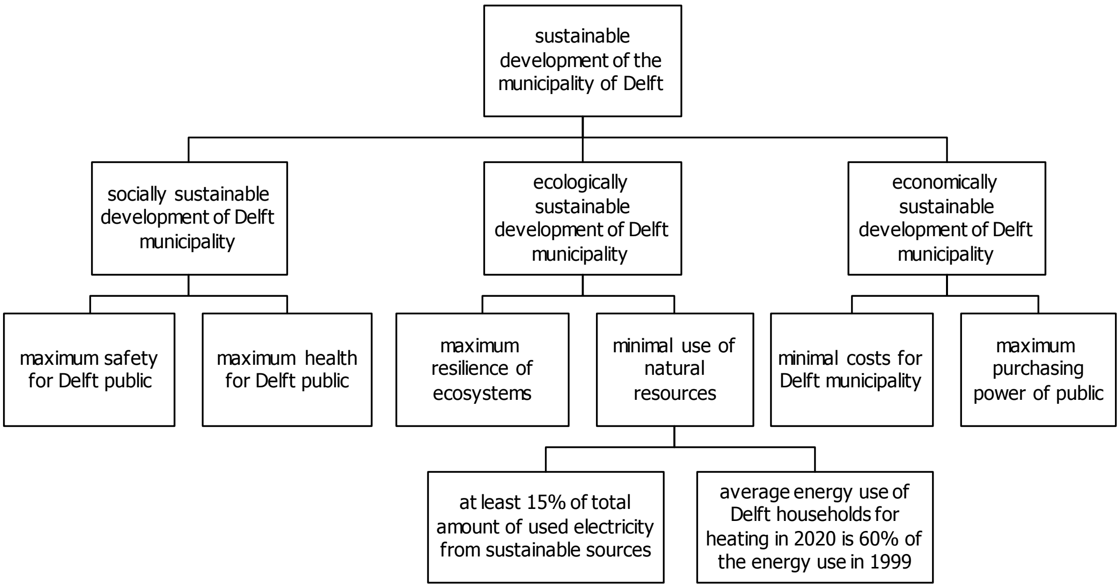

Figure 13. Objective tree Delft municipality

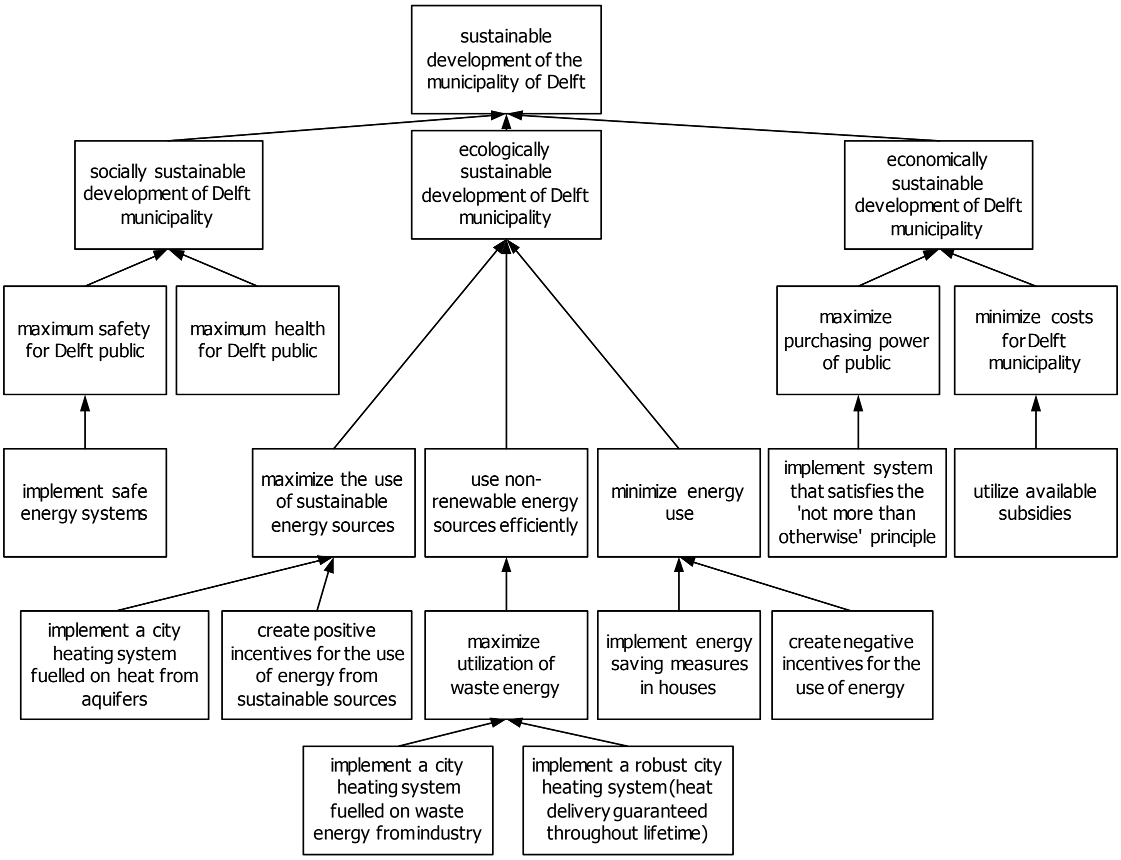

Figure 14. Means-end diagram Delft municipality

The future network operators problem statement is: *Which energy system can the municipality of Delft best apply for city heating with waste heat, that is viable for a future network operator?*
The main performance indicators are:

- Total benefits for the future network operator – total costs for the future network operator
- Robustness of city heating system

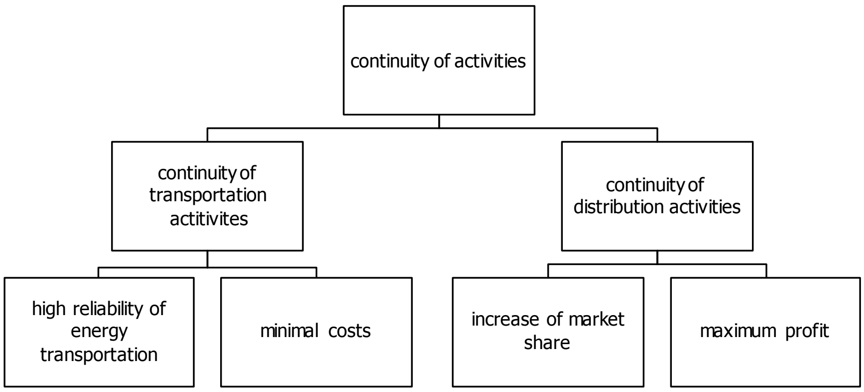

Figure 15. Objective tree for a vertically integrated network and distribution company

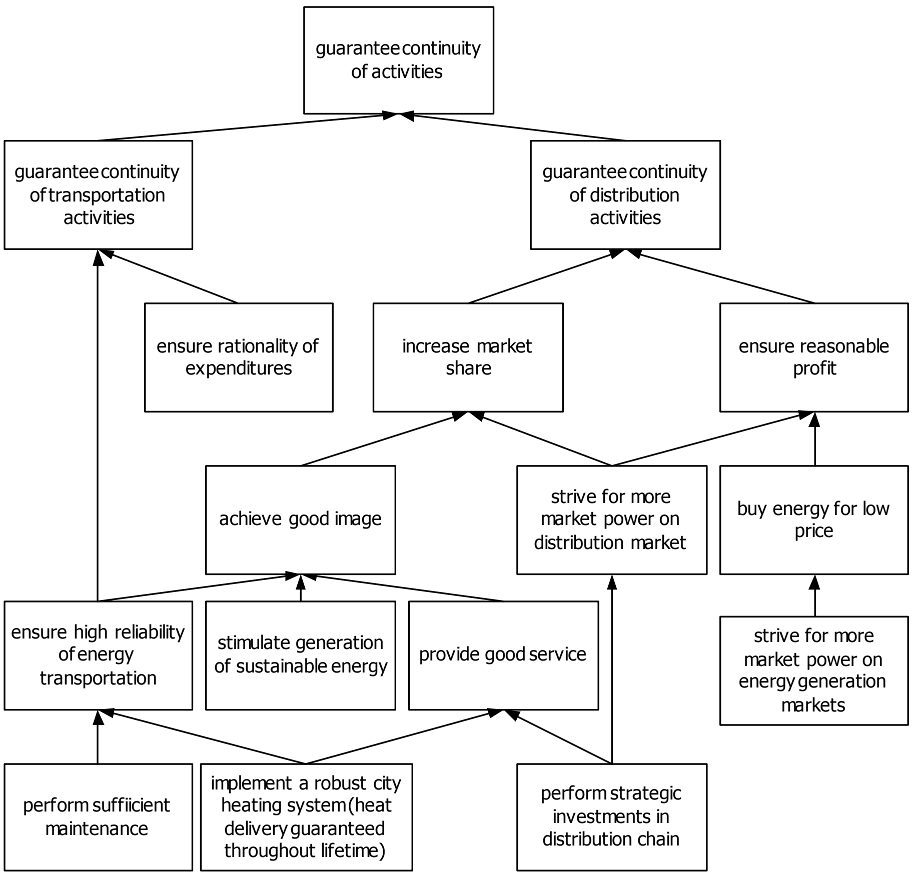

Figure 16. Means-end diagram for a vertically integrated network and distribution company

The housing corporation's problem statement is: *Which energy system can the municipality of Delft best apply for city heating with waste heat, contributing to the quality and value of the houses, without harmful consequences for lettability of the houses and discomfort for the residents?*
The main performance indicators are:

- Contribution to the value of the houses
- Total benefit for housing corporation – total costs for housing corporation
- Total benefit for households – total costs for households
- Robustness of city heating system

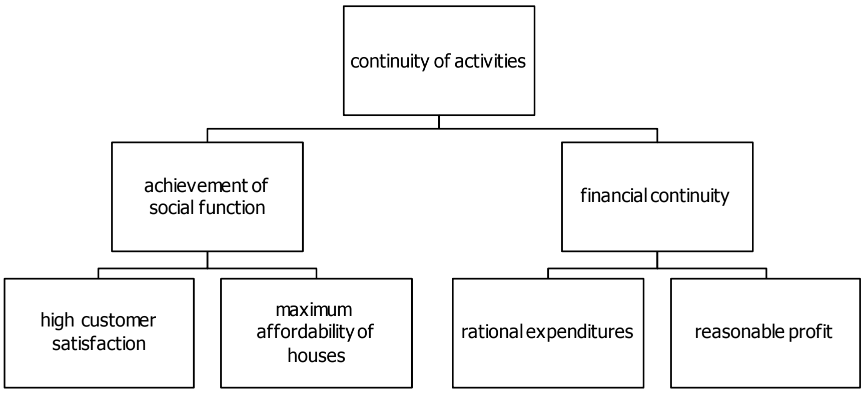

Figure 17. Generic objective tree housing corporations.

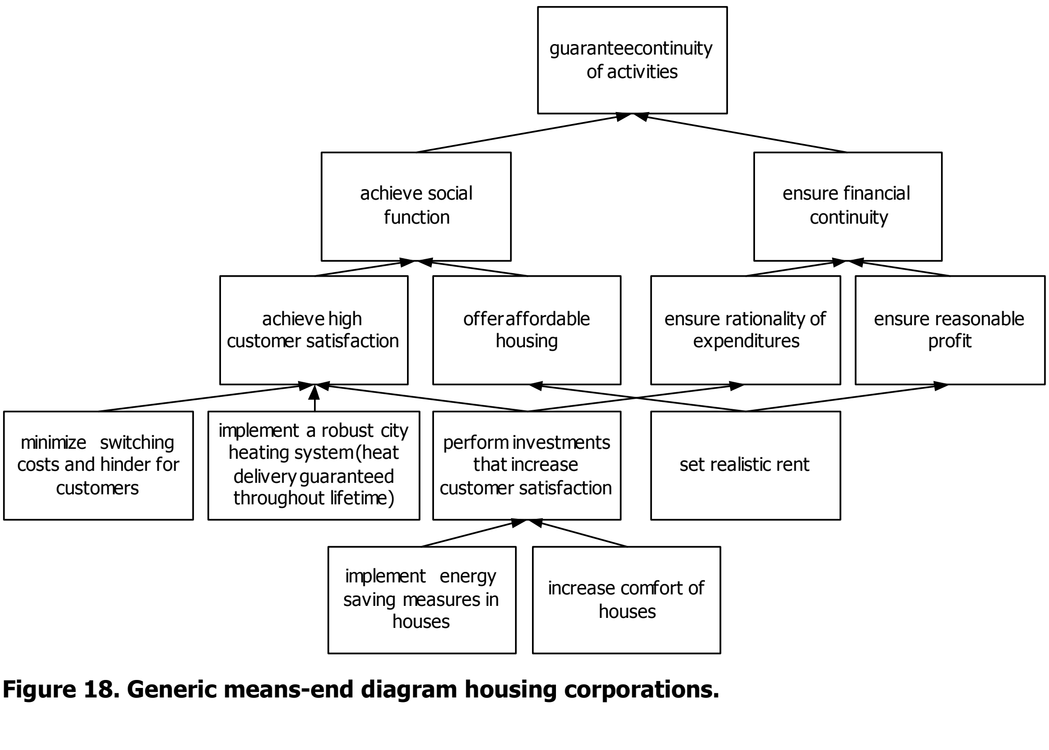

Figure 18. Generic means-end diagram housing corporations.

The heat supplier's problem statement is: *Which energy system can the municipality of Delft best apply for city heating with waste heat, contributing to reduction of CO_2 emissions of the plant, without harmful consequences for profitability and operability of the plant?*
The main performance indicators are:

- Plant energy savings
- Contribution to reduction of CO_2 emissions
- Total benefit for heat supplier – total costs for heat supplier
- Effect on plant operability

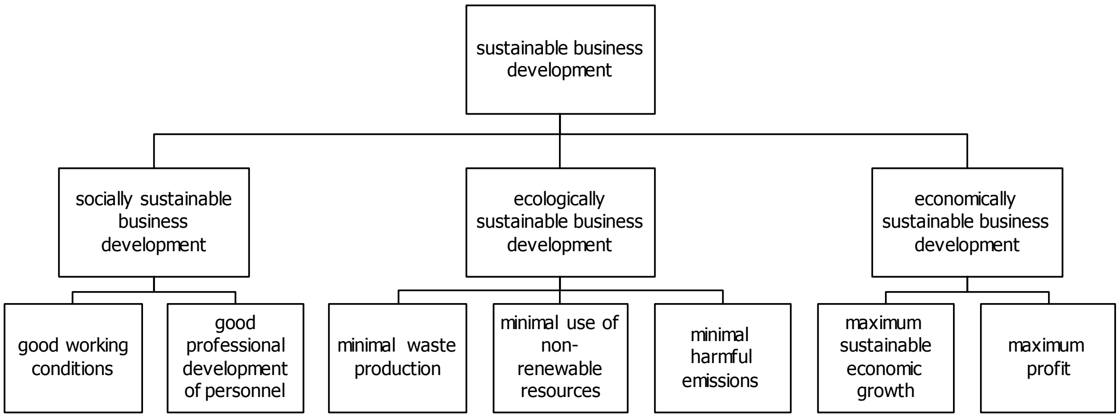

Figure 19. Generic objective tree heat suppliers.

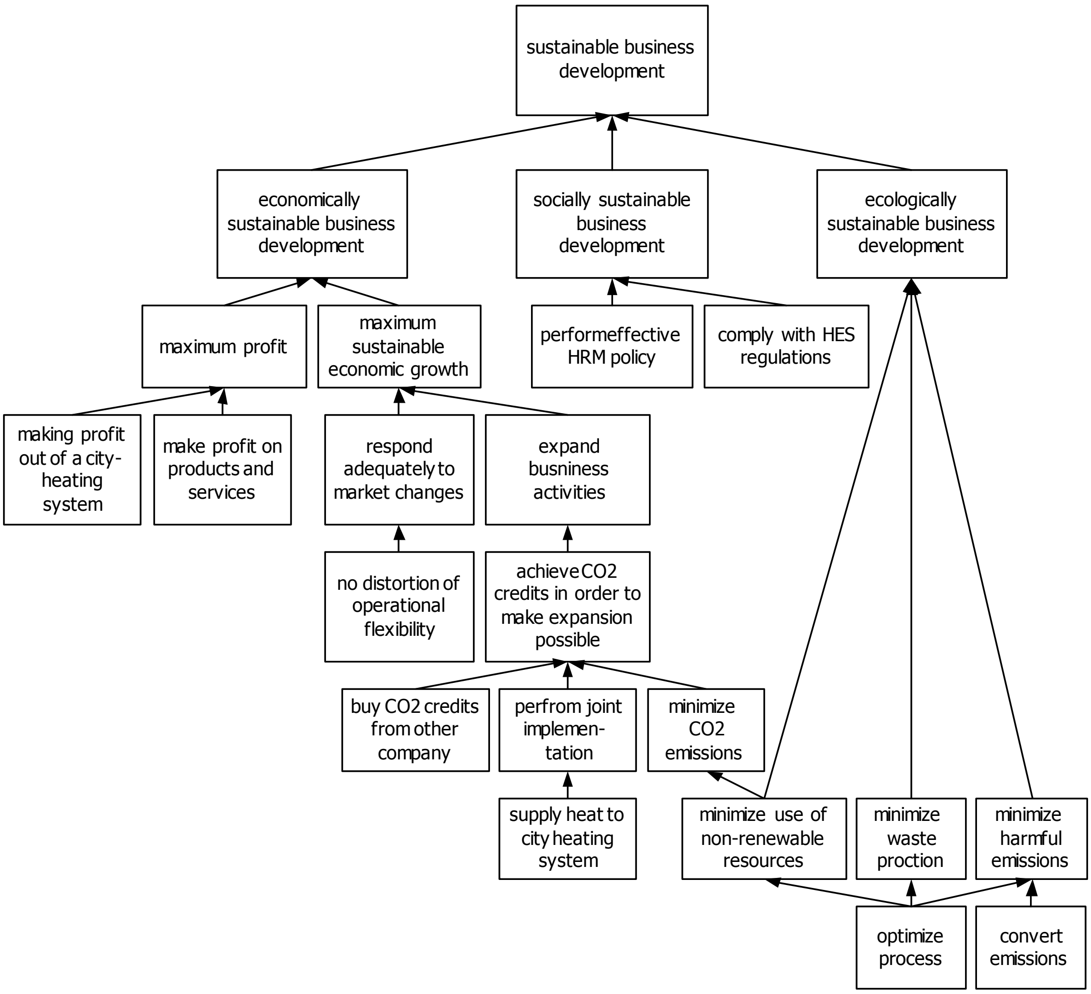

Figure 20. Generic means-end diagram heat suppliers.

Scenario of actor group

Dependent on the selected alternative, different groups of critical actors will form the centre of the process. Here we briefly describe the consequences for the process design for a fictional alternative. When the alternative is selected where the wastewater of DSM Gist will be used for the city heating of De Poptahof, the formation will exist for example of the heat supplier DSM Gist, the housing association Vestia, a network operator and a developer. This will have several consequences for the process. DSM Gist possibly sees a decreasing operational flexibility and increasing costs when they participate in the city heating system. In order to convince DSM Gist, the municipality should point to the rewards they receive for their delivered heat, the achievement of CO_2 credits and image improvement. Vestia will consider high investment costs as a possible problem for participating. This may raise the rents. To convince them of participating anyhow, Delft municipality should point to the innovative character of the project, since Vestia has its own project development unit. Also the quality improvement of their buildings should be emphasized. For the future network operator, participating must mean prospects on profits. When this network operator will be another company then the current, Eneco, Delft municipality should offer Eneco (financial) compensation.

Appendix 3: Discovering technical requirements

List of requirements

Bahill and Dean (1999) have made a list of requirements which is a good reference to create a complete list of constraints and goals. With this list in mind you can more easily find missing requirements. The following is a selection that we deem relevant for this design:

- Input-output requirements: a description of the transformation(s) to be performed by the system;
- Technology requirements: the components that can be used to build the system (hardware, software, bioware);
- Performance requirements;
- Cost requirements
- Trade-off requirements
- System test requirement (how the system will be tested)
- Policy requirements (institutional and process requirements)
- Customer requirements
- Environment, health and safety requirements
- Intangible requirements (ethics; aesthetics)
- Laws and standards requirements
- Legacy requirements (requirements imposed by previous systems)

Storyboards

From storyboards, a story of how an imaginable future system would work, you can distillate requirements in a creative way. It's a creative method for completing the list of requirements. The following three storyboards were written for the technical requirements:

1. Energy from Plant A, used for nearby City heating

The energy used to heat a residential area of 2000 houses is supplied by Plant A through a closed pipe system. All houses are within 2 kilometers of Plant A.
The group risk and individual risk of citizens are studies on and are within the acceptable range, set by the Dutch government. Citizens asked for this survey, while they did not want an increased risk by the energy system.
The supply has been secured for a period of 20 years. The municipality of Delft has arranged something for after this period. The systems capacity is around the expected peak demand, augmented with a grow margin of 30%.
Because the processes of Plant A are continuous and have proven to be very reliable, no storage or backup facility is needed. Plant A guarantees a reliability of 99,5%. The surpluses of water and energy are dealt with internally, while this was done also before the energy system was built. That's why the temperature and water flow is constant.
The system works with the regular radiator system, which was installed already. Because of the high temperature heat this is the most convenient way.

2. Users experience with floor heating

A new thermostat has been installed at the transfer to the new system. This is a user friendly and simple device, which regulates a valve at the supply point of the closed water system in house. While a form of floor heating is used the in house system is even more efficient and comfortable then a radiator-based system.

3. Accident

The system is down for on a very cold day because of a reactor failure. No heat is delivered. While the system does not include electricity deliverance and hot drinking water deliverance the problems are quite small. Citizens improvise by using boiled water and electrical devices to make it warm. They are not completely dependant on heat delivery from one source. The municipality and the energy delivering company get many complaints, but citizens are not really upset. They are thankful for the information service which tells us the expected duration of the systems error.

Legend for system diagrams

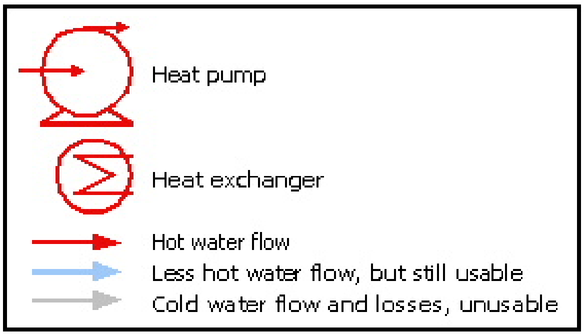

Figure 21. Legend for system diagrams.

Appendix 4: Institutional analysis

This institutional analysis elaborates upon the four levels of analysis or design with regard to the functioning of complex (technological) systems of the model of Williamson (1998), see also table 1, paragraph 4.2

Level 1: The informal institutions

The informal institutions have an important influence on the perceptions and preferences of different actors. The informal institutions are the values, norms and culture that exist. For the design of the city heating system the value that is most important is the increasing environmental concern in our society. Environmental friendly products and the 3E plan of Delft are all examples of this concern. Together with this concern goes the realization that our resources are limited and will not last forever. People nowadays want to take their responsibilities and set an example to the world by making innovative improvements. Image is very powerful these days and an environmental friendly image is good to have. The Dutch 'poldermodel' also plays an important part since many parties are involved in the design of the system and their opinions are taken into account. The Dutch government is stimulating the innovativeness of the economy by setting up an innovation platform. Innovation is therefore also an important value that has to be taken into account.

Level 2: The formal institutions

At this level the formal rules of the game are described, the legal positions of the players and the regulatory regimes available to coordinate transactions are determined.

First a summary is presented of the relevant policy notions for the development of energy systems that use waste heat for household heating. Several levels can be distinguished. First of all, the main global protocol is the Kyoto Protocol. This protocol is accepted in 1997 and signed by 84 countries. The EU and its Member States ratified the Kyoto Protocol in late May 2002. The Netherlands has committed itself to a 6% reduction of greenhouse gas emissions between 2008 and 2012, relative to 1996 emissions. The main greenhouse gas is CO_2, which is emitted upon burning carbon-containing fuels, such as oil, natural gas and coal. On the EU level, Greenhouse Gas Emission Trading has been setup to create financial incentives for efficient allocation of the allowable greenhouse gas emission (see 2003/87/EG). The Kyoto agreed emission reduction can be achieved through trade of emission rights, of which a fixed maximum is set by government. There are several measures to increase flexibility of the system and its users: Joint Implementation and the Clean Development Mechanism. The Nederlandse Emissieautoriteit (NEa) is the Dutch installed organization, which looks after the (still to be developed) emission trading systems. Appendix I of 2003/87/EG contains the businesses that are included in this emission trading (340 firms which account 45% of the total CO_2 emission). Also directive 2004/17/EC contains the rules of public procurement procedures.

The Dutch environmental policy is set out in the Fourth National Environmental Policy Plan (Nationaal Milieubeleidsplan 4 or NMP-4 in short). Within the Netherlands the Besluit Aanleg Energie-Infrastructuur (BAEI) has been setup in 2001 to increase sustainability and environmental friendliness (see Novem, 2005). BAEI deals the design and redesign of areas with more than 500 houses or 25.000 m^2 of utility buildings. BAEI applies only for complete energy infrastructures. Only-heat networks are not supported. The ministry of EZ is also currently working on a proposal to regulate the tariffs at the heat market. They are focusing on cost oriented regulations; setting tariffs for production and distribution. For the distribution of heat they propose the same tariff system as for electricity and gas (DTe, 2004).

On the Province level the National Environmental Policy Plan is implemented in the Beleidsplan Milieu en Water (see Provincie Zuid-Holland, 2005). A large number of projects are supported through this notion until 2004. Other notions are the Streekplan, Energietoets, Energie Prestatie Keur (EPK) and Toetsing milieuvergunning.
On the municipal level the 3D plan is important, which is detailed per theme in the 3E plan (see Gemeente Delft, 2003). This plan contains several projects related to the type of systems to be designed in this project. It includes the use of waste heat of DSM Gist, use of sustainable energy in rural areas and control of energy use in municipal buildings.

Level 3 and 4: Institutional arrangements and actors and games.

The design space at the third level is described in the main report paragraph 4.2. The individual actors and their interactions of the fourth level are described in detail in the process design (see Table 6 in Appendix 2).

However an explanation of the possible governance structures will be given here. This explanation is based on Williamson (1979) and Mathissen (1997).
A classical contract is a simple market contract. This type of governance structure is efficient for standardized transactions (low asset specificity, low uncertainty, frequency is unimportant). A neo-classical contract is a complex market contract for occasional, non-standardized transactions. It is efficient in a market with medium uncertainty and medium to high asset specificity. A trilateral neoclassical contract is suitable in case of low frequency. A bilateral neoclassical contract is suitable in case of high frequency. An example is franchising. A relational contract is suitable for recurring, non-standardized transactions. The main example is vertical integration, nexus of contracts.

Public-private partnership is a form of relational contract. A new organisation is formed for a specific purpose. The type of contract used in public procurement procedures depends on the type of market and on the degree of tendering. For Delft municipality one of the possible institutional solutions is using the market and applying the possibility of tendering. In the EU Directive 2004/17/EC on the public procurement procedures in "special sectors" of water, energy, transport and postal services the rules for tendering are described. There are different degrees of public procurement, depending on what activities are outsourced e.g. construction, maintenance or operation and different public procurement procedures: the open procedure, the restricted procedure, and the negotiated procedure with or without the publication of a public contract notice. The municipality of Delft or in the case of Rotterdam, the Transportation Company can choose to invite tenders for the building of the city heating system. By offering firms the possibility to present different proposals, the municipality obtains a large variation of customers. This provides them the opportunity to choose the most suitable firm for the most favourable price. On the other hand for the firms, the system of tender guarantees openness with the assignment of projects and equality of chances. Thus, also new firms in the market get the possibility to join. The problem however is that with a system as complex, uncertain and infrequent as this it is very hard to create complete contracts. Of course the municipality can also choose for one of the other mechanisms, for example the bi-lateral system by creating a joint venture and performing the necessary operations together with the main building company. This could be useful if the municipality also has plans for restructuring other residential quarters and wants to keep the necessary knowledge within their organisation. The notion of transaction costs is also useful when considering institutional arrangements between project developers, housing corporations, energy companies etc.

Appendix 5: List of performance indicators

1. The amount of energy used:
    - The amount of unused energy (total fossil input before – total fossil input after implementation)
    - The amount of energy saved (total input before – total input after implementation)
    - Energy efficiency (total usable energy out / total energy input)
    - Total energy delivered by city heating system in Delft compared with total energy use in Delft (kWh / kWh)
2. Environmental impact:
    - Emitted CO_2 (ton / kWh),
    - Avoided emitted CO_2 per total emitted CO_2 in Delft (ton / ton)
    - Emitted CO_2 (ton / investment costs)
    - Local NO_x emissions (ton / kWh)
    - Avoided emitted NO_x per total emitted NO_x in Delft (ton / ton)
    - Regional environmental impact due to heat dissipation (grade 1-10, f($T_{max, outer layer of pipeline}$, ecological sensitivity of surrounding soil))
3. Robustness
    - Long term robustness: Reserve margin city heating system: energetic capacity – expected peak demand) / energetic capacity (kWh / kWh)
    - Seasonal robustness: (peak heat demand winter – peak heat demand summer) / reserve capacity (kWh / kWh). Reserve capacity = operational reserve capacity + storage capacity.
    - Daily robustness: max standard deviation in house temperature that can be achieved by the system / standard deviation of households (–)
    - Redundancy of the system: number of sources (#), number of sinks (#)
    - Reliability of sources: downtime for each source/total time (hours / year)
    - Flexibility of sources: the fastest rate of changing output (kWh / hour)
    - Perceived diminished operational flexibility of sources (grade 1-10)
4. Average temperature of delivered heat (^{o}C)
5. Safety of the system: Group risk: Number of death by accident * probability of accident per year (# / year)
6. Systems lifetime (year)
7. Costs:
    - Depreciation investment costs (euro / year)
    - Maintenance costs of non-user appliances (euro / year)
    - Energy costs for consumers (euro / kWh)
    - Energy costs before – Energy costs after implementation (euro / kWh)
    - Amount of subsidies per investment costs (euro / euro)
    - Expected value of achieved CO_2 certificates (euro/investment costs)
    - Maintenance costs user appliances (euro / (household * year))
    - Depreciation fixed user investments costs (euro / (household*year))
    - Downtime during transition (hours)
    - Hinder during transition (hours)
8. Suffice laws and regulation
    - Be in accordance with all national, European and global laws
    - Perceived presence of trust (grade 1-10)
9. Perceived fairness of tariffs (grade 1-10)

10. Perceived goodness of fit of the organizational (governance) structure by the stakeholders (grade 1-10)
11. Perceived freedom of choice of heat deliverer for end consumer (grade 1-10)
12. Perceived support from stakeholders (grade 1-10)
13. Involvement of critical actors: amount of critical actors active in decision making process (%)
14. Perceived ease of entry and exit (grade 1-10)
15. Acceptance of protection of core values (grade 1-10)
16. Perceived satisfaction of the choice for a process manager (grade 1-10)
17. Acceptance of consulted experts (grade 1-10)
18. Perceived clarity of process (grade 1-10)
19. Perceived effectiveness of process (grade 1-10)
20. Progression of process (# contracts / process step)

Appendix 6: Argumentation for score card

The five alternatives are screened on the four criteria from chapter 3. Below a description of the derivation of the scores is given. The description of alternative 5 (do nothing) is left out, since the characteristics for this situation are already described in the problem analysis.

Alternative 1: Many sources, many sinks

- Robustness: A system can be described as robust when it is able to accommodate fluctuations in demand and when it contains back-up sources. Since in a system with many sources, possibilities for accommodation are abundant, alternative 1 can be considered as very robust.
- Total benefits – total costs: Even though the total costs will be higher if multiple sources need to be connected to multiple sinks, the benefits are also higher, since more houses are attached to the system. That is why the overall cost benefit ratio is ranked as pretty good.
- Compliance to interests of critical stakeholders: In a system with many sources and sinks a variety of actors are involved. All the heat suppliers are served as well as the housing associations. The developers will consider it as positive, since the more sinks added the more money they will make from their activities.
- Contribution to reduction of CO_2 emissions: The more sources and sinks are added to the city heating system, the more efficient energy is used and therefore this alternative can be considered as contributing significantly to the reduction of CO_2 emissions

Alternative 2: Many sources, one sink

- Robustness: Since in a system with many sources possibilities for accommodation are abundant, alternative 2 can be considered as very robust.
- Total benefits – total costs: A system with many sources, but only one sink can be considered as robust. However, when the greater part of these sources only function as reserve capacity, this leads to a financial unfavourable situation.
- Compliance to interests of critical stakeholders: Since there is only one sink served with the city heating system, resistance can be expected from at least the housing associations.
- Contribution to reduction of CO_2 emissions: The sources that are added to the city heating system contribute to a more efficient use of energy and therefore contribute to the reduction of CO_2 emissions. However, since there is only one sink added, this contribution will be low.

Alternative 3: One source, many sinks

- Robustness: Since in a system with only one source less possibilities for accommodation are abundant, alternative 3 can be considered as not robust.
- Total benefits – total costs: The cost - benefit ratio is very positive for this alternative. Because only one pipeline is needed and many houses can be connected to the system.
- Compliance to interests of critical stakeholders: Since only one source is joining the city heating system, resistance can be expected from at least the heat suppliers.
- Contribution to reduction of CO_2 emissions: When many districts are added to the system, all these districts use the energy more efficiently than in the current situation. Therefore, this alternative contributes to the reduction of CO_2 emissions.

Alternative 4: One source, one sink

- Robustness: Since there is only one source and one sink, there is a very small flexibility, no possibilities for accommodation exists and therefore this alternative has a very low robustness.

- Total benefits – total costs: In a system with only one source and one sink, less investments has to be made for implementing the system.
- Compliance to interests of critical stakeholders: Since there is only one sink served with the city heating system and one source used, resistance can be expected from actually all the critical stakeholders.
- Contribution to reduction of CO_2 emissions: The contribution is rather low, because the heat is only used for one sink instead of for multiple sinks.