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Planning heat sensitive cities: an approach towards sustainable energy systems

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Abstract

Faculty of Spatial Sciences and Department of Business Administration, Economics, and Law

Master of Science

Planning heat sensitive cities: an approach towards sustainable energy systems

by Jakob Knauf

The search for renewable energy sources is nowadays on the global governance agenda. In northern European residential and office areas 70 % of the total energy consumption is linked to heating or cooling processes. Most of the energy consumed in these processes is provided by fossil fuels. One promising concept in spatial planning is the urban harvesting approach. This concept suggests to harvest residual resources which are currently seen as waste but still have some remaining quality. The further reuse of waste heat energy in urban areas and the exergy principle might be of special interest in order to find alternatives to fossil fuels. In current urban processes high quality energy sources like gas and oil are often used for purposes which do not need that high quality. Space heating is one example. Heat energy for this process could be provided through harvesting residual heat. The proposed approach in this study uses the idea of resource exchange between various urban functions. It is tested in a case study of the district St. Johann in Basel, Switzerland. The study illustrates that visualizing urban functions and their potentials on a map can help planners to draw lines between sink and sources of energy. These linkages are not the same all year but can vary between seasons. The study furthermore indicates that water infrastructure can take a key role in developing these energy linkages. Water and heat energy are closely linked. Both together are not considered much in spatial planning yet. This study introduces the concept of heat sensitive cities which proposes to link water, periodicity and waste heat energy.

Keywords: Spatial planning, Heat energy, Urban harvesting, Exergy, Water bodies and infrastructure, Periodicity, Heat grid, Heat sensitive city

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Abbreviations

UHA	**U**rban **H**arvest **A**pproach
HES	**H**eat **E**nergy **S**ystem
HSCA	**H**eat **S**ensitive **C**ity **A**pproach

Chapter 1

Introduction

The current energy landscape in cities is strongly dependent on fossil fuels (Droege, 2002). Their use is for some reasons critical: First, fossil fuels are a main contributor to climate change. Second, natural fossil fuel resources are limited. Third, fossil fuel resources are limited to certain countries like Saudi Arabia, Iran and Russia (natural gas). High demand for fossil fuels leads to dependence on these countries (de Boer and Zuidema, 2015). The search for more sustainable alternatives through renewable energy sources is nowadays on the global governance agenda. A sustainable resources management through harvesting local renewable and residual resources might contribute to a less dependency on fossil fuels (Leduc and Van Kann, 2013).

There are different resources that could be harvested. Next to matter like residential garbage also energy can be recycled. In the European Union, the industry sector is responsible for about 26 %, the transport sector for about 33 % and other sectors for about 41 % of the total energy consumption. 22 % of the total energy is consumed by residential areas. While in the transport sector 93 % of the energy is based on crude oil, gas is mostly used in industry and residential areas. 32 % - 34 % of the energy consumption in industrial and residential areas is based on gas while another 32 % comes from electricity. The other 25 % is based on energy carriers from renewable and non-renewable, other fossil fuels and derived heat energy (eurostat, 2016).

The statistics indicate that most energy is not based on electricity but on chemical energy carriers. Their consumption is in most cases connected to combustion processes in which heat energy is produced. The further reuse of heat energy in urban[1] areas might be of special interest in order to reduce fossil fuel consumption. In northern European residential, commercial and office areas 50 % of the energy is used for space heating and cooling. Another 20 % is used for tap water heating. Electricity for lighting and machines accounts for 30 % of the energy consumption (Pérez-Lombard et al., 2008).

1.1 Problem statement

In heating processes, high quality energy is often used for purposes which do not need that high quality (Agudelo-Vera et al., 2012). The combustion of gas in house heating systems for example produces flame temperatures of 1000° C (Vandevyvere and Stremke, 2012). This temperature is used in residential and office buildings to heat water up to a temperature of 65° C. This temperature is needed for processes like showering and washing (Groothuis et al., 1985; Yao and Steemers, 2005). For space heating in modern systems 35° C supply temperature is sufficient (Leonhardt and Müller, 2010). The use of high quality energy resources reveals two main issues: high quality energy resources are often fossil fuel based and high quality energy are used for heating processes that do not need that high quality (Balaras et al., 2005; Agudelo-Vera et al., 2012). The first issue relates to the dependency on fossil fuels that should be reduced due to the mentioned reasons. The second issue is linked to thermodynamic laws, especially the second law. While the first thermodynamic law states that no energy can get lost in transformation processes, the second thermodynamic law limits the transformability of energy. Taking the second law into consideration can help to "increase efficiencies of energy conversion and material processing significantly" (Stremke et al., 2011). The idea is that energy is used that fits the quality purpose. This means that high quality energy is used for processes that have high quality energy demand. Processes with lower quality demand are supported with lower quality energy.

The urban harvest approach (UHA) is a concept that introduces the reuse of residual resources. Urban harvest strategies can be used to identify and use residual waste like heat energy in order to use energy effectively and efficiently. Some processes need high

[1] In this study both terms urban and city are introduced and used as synonyms. They are not linked to specific characteristics and definitions like population size or administrative boundaries and are not seen as the opposite of rural. Urban areas and cities are rather used in this study to describe the agglomeration of different urban functions.

quality energy. For example, in chemical companies or power plants natural gas or other fossil fuels are used. As the first thermodynamic law states, energy gets not lost but only transformed. The waste from high energy processes can still be used for processes with lower energy demand. The second thermodynamic law states that this is not possible the other way around. Applying the second law to heat energy means that high quality energy carriers like gas should be used for processes that need high quality energy. Heat energy waste from high quality energy processes in for example chemical factory can be harvested and used for heating an aluminum processor first, then a bakery, a brewery, and finally residential areas (Leduc and Van Kann, 2013). Instead of using gas to heat all the mentioned urban functions[2] separately, only the chemical factory is powered by high quality energy while the other urban functions are using residual heat energy. This can help to create sustainable heat energy systems (HES) (Hepbasli, 2008; Rosen and Dincer, 2001). Sustainable HESs should help to ensure that resources are used and managed in a way that it does not impede the future generation's ability to satisfy their need. This includes for example the reduction of high fossil fuel consumption in order to spare resources, reduce CO_2 emission and decrease social and economic dependence.

However, one issue in creating linkages in HESs is that heat energy demand and source can vary in urban areas within a year. The heat demand in northern Europe is especially an issue in winter whereas in summer cities suffer from heat island effect. "Urban Heat Island (UHI) is considered as one of the major problems in the 21st century" (Rizwan et al., 2008). This means that in order to create linkages between heat energy demand and sources periodicity must be considered.

Furthermore, heating processes are often connected with water. Water is for example often used to distribute heat energy in buildings for space heating. But also other processes like washing and showering are water related. The reason of water as heat energy carrier is, next to its broad availability, its capability to function as a major storage of heat energy. The heat capacity of water is more than four times higher than of air and three times higher than many soils (Porges, 2001; Manteghi and Remaz, 2015).

The strong connection of water and heat energy gives references that in order to harvest waste heat energy, water should be considered. This water is however not only limited

[2]The term urban function is used in this study to distinguish between land use patterns: residential houses, office buildings, parks, streets etc. (Leduc and Van Kann, 2013; Agudelo-Vera et al., 2012). It is therefore used to assign land use characteristics to the entities of the urban fabric.

to single urban functions. Water is distributed and collected in the urban fabric by systems. The provision and treatment is performed by central entities. This means that strategies for harvesting waste heat energy is not limited to single urban functions but can be a spatial issue. The wastewater system is for example a system that extends through the whole urban fabric. It therefore creates a spatial connection between single urban functions. This connection is, however, not bidirectional. Water is as a result of gravity flowing in one direction. It therefore connects higher altitudes with lower ones.

Analyzing further the urban fabric, it becomes apparent that there are additional water bodies like rivers, lakes, and channels that might be included into heat energy analysis. Their management is, however, complicated. Many different aspects like flood protection, supply and health security, recreation and other aspects must be considered. The different functions that water can have and the efforts to ensure these let to a separation and fragmentation of the water management into many different institutions and entities. This impede integrated management and using the same water bodies for different purposes. The wastewater system is for example mainly used for transporting water in order to purify it. The aim is to get rid of the pollutants and not to see these as resources.

There are, however, studies that prove its high energy potential (Meggers and Leibundgut, 2011). This could be used in an UHA. Also other water bodies have high potentials. In Kingston, UK, heat energy is for example extracted from the river Thames and used to heat a building complex with apartments and a hotel. This example shows that heat energy potentials are therefore not only characterized by its heating but also its cooling capability. There are more of these examples like in Duindorp, the Netherlands, Portsmouth, UK, and Stockholm (Värtan Ropsten), Sweden (Cao et al., 2009; Goodier et al., 2013).

All these examples illustrate that 'second law thinking' can help to find alternatives for fossil fuels. However, this thinking is at the moment mainly considered for single projects. A general spatial planning approach which includes different water bodies is, however, missing. Such an approach is however essential because "the competitiveness of societies will depend on how efficient the stocks and flows of the urban fabric are managed and on the ability to adapt the urban fabric to change" (Deilmann, 2009). Finding strategies in spatial planning in order to manage flows, for example of energy and water, is therefore important for future societal development.

1.2 Research aims and objectives

The main issue discussed in this study is that 'second law thinking' is already applied in some projects. However, it is not yet well understood in spatial planning (Stremke et al., 2011). This can be problematic because exergy and 'second law thinking' are closely connected with sustainable development (Dincer, 2000).

This study has the hypothesis that spatial planning can help to develop strategies to harvest and use heat energy potentials from urban water bodies. In this study the term strategy is linked to an analytical approach that can be used to analyze the urban fabric and show heat energy potentials especially in water bodies. This spatial planning approach can be utilized to create energetic linkages and reduce fossil fuel consumption. Furthermore, spatial interventions can through the design of the urban fabric create potentials. Spatial planning can therefore help in planning processes to show opportunities and create a basis for strategic decision making. Water bodies, especially water infrastructure, underground aquifers and surface water bodies can contribute to create sustainable HESs. HESs are entities consisting of several urban functions that create through their spatial connection a system. This system is sustainable in terms of reducing fossil fuel consumption and decreasing dependence on these.

The aim of the study is to introduce a spatial planning approach that uses the idea of harvesting residual heat energy with special focus on water. The approach should allow to exchange heat energy potentials between various urban functions in order to create sustainable HESs. The use of urban water bodies and its contribution to heating processes should be analyzed. This study should moreover develop suggestions for spatial planning practice to use water as means of transport for heat energy. Furthermore, the relevance of including periodicity into spatial planning for heat energy analysis should be elaborated. The term heat energy potential in connection with water as means of transport is in this study linked to both cooling and heating capabilities. For better readability this study uses only the term heat.

1.3 Research questions and thesis structure

This chapter is aimed to describe how the hypothesis is going to be tested and which research questions should help in order to do so.

The research questions for this study are the following:

1. What variables are important to identify and use urban heat energy potentials in order to create sustainable HESs?

2. How can a spatial planning approach help to develop a sustainable HESs and what are the benefits of such a system?

3. What findings can be derived from the spatial planning approach and the case study in order to identify the contribution of urban water bodies towards sustainable HESs?

This study proposes a methodology consisting of two parts in order to verify the hypothesis. In the first part a six step approach, which was developed out of the literature from the theory chapter, is going to be introduced. Findings from sustainable urban energy development, thermodynamics and heat including the exergy principle, urban water use and infrastructure, and the characteristics of spatial planning on energy networks are used. This approach should help planners to identify, link and connect heat energy sources and sinks. In a second step the six step approach is going to be illustrated and presented in one case. Data usable for this specific case and generic information which can be used for other cases are collected. Visualization of the findings on maps will be used. This should help to present the results, identify the spatial distribution of heat energy, show possible and reasonable energetic linkages and work out periodical differences of the linkages. After the presentation of the results and subsequent discussion, the conclusion and findings for spatial planning theory and recommendations for spatial planning practice will be introduced.

It should be finally stated that spatial planning connected to energy interventions should "always be socially acceptable, economically feasible and not harmful to biodiversity" (Stremke et al., 2011). However, these aspects could not be tested in this study.

Chapter 2

Theories

This chapter is meant to introduce theories that are used to build the methodological foundation of this study. The theories are furthermore used to illustrate what is already known about spatial planning and its potential to create HESs. The theory will be further used to design a spatial planning approach.

2.1 Sustainable urban energy development

Cities have currently an unbalanced energy use. On the one hand they need many resources to maintain functional and produce on the other hand high amount of waste. The use of energy and matter have often linear characteristics from resources use to waste production without any feedback loops, nor quantitative or qualitative (Guy and Marvin, 2000). This need for resources make cities highly dependent on a constant inflow stream of materials and energy from other cities and hinterlands (Rovers, 2007).

The current resource use of cities was described by Noorman and de Roo (2011) as second energy landscape in which production and use of the resources are decoupled. This is in contrast of the first energy landscape which had a strong connection between energy systems and physical landscapes. Cities were only able to use the sort of resources the physical environment provided for them in direct proximity. Among these resources were for example peat, wood, hydro energy and wind. All sources of energy had in common that they were not easy to transport so that energy production and use had to be close together (Pasqualetti, 2012).

High power density resources like coal, oil and gas made long range transportation of energy resources possible so that production and consumption got spatially separated (Pasqualetti, 2012). These resources started the creation of second energy landscape. The availability of high power density resources without the dependency on the physical landscape made cities major users of energy beyond their natural and spatial capacities. Natural processes could not supply and recycle all the matters which were used in the urban fabric any more (Agudelo-Vera et al., 2012; Leduc and Van Kann, 2013).

The high consumption of "oil, fresh water, phosphorus, metals; and the disruption of natural cycles, for instance nitrogen and carbon-cycle"(Agudelo-Vera et al., 2012) turns cities into primary sinks of resources (Xu et al., 2010).

Following the Brundtland commission this development into the second energy landscapes is not sustainable. "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Commission, 1987). The reason is that exploitation of resources is unsustainable because the resources availability for future generations is at risk (Opschoor and Reijnders, 1991). Sustainable urban energy systems are therefore systems that meet the demand of the current generation without undermining the supply of future generations. Threats that might compromise the future generation ability are for example: climate change due to CO_2 emissions, depletion of resources, pollution, and social and economic vulnerability because of resource dependence (Yamaguchi et al., 2007; Omer, 2008; de Boer and Zuidema, 2015).

It is predicted that urbanization will continue in future. In 2014 about 54 % of the world's population was living in cities. It is expected that by 2055 66 % of the world population will reside in urban areas (Nations, 2014). This makes the unsustainable urban resource use more and more an important global issue for planners. Harvesting of urban resources can, next to a more efficient resource management, play an important role towards sustainable urban energy and matter systems (Agudelo-Vera et al., 2012).

The UHA is grounded on the idea that waste is nothing less than an outflow of matters and energy which still has some quality. This outflow has lower quality than the original inflow but is still high enough to reuse it within the urban system. These secondary resources can break the linear resource use (Zhu, 2014; Agudelo-Vera et al., 2012). Secondary resources have the benefit that they reduce the demand for primary resources like fossil fuels. Therefore CO_2 emissions, the depletion of resources and dependence on resource supply decrease.

2.1.1 Urban metabolism

In order to understand the energy processes in cities, some principles and assumptions of the functioning of urban energy and matter transformation might be useful for further understanding. The following paragraphs should give an overview of energy loss, metabolism and harvesting. In chapter 2.2 a quantitative approach for measuring quality and thermal energy loss will be introduced.

Loss of quality

Energy and matter in cities are generally delivered and distributed through a system of pipes, wires etc. The quality of the matters, e.g. gas and water, must be delivered for costumers at the highest quality demand because often systems can only provide one quality (Leduc et al., 2009). There is for example only one system for providing freshwater to residential houses. To achieve such high quality, the original quality of the resources needs to be upgraded. Water from rivers or groundwater for example must be cleaned and disinfected. This purification step in necessary to feed the network with constant quality. The purification process however consumes energy and materials (Leduc et al., 2009).

On the demand side consumers require different qualities. For drinking water for example high water quality is needed. Flushing the toilet on the other hand does not demand that high quality. However, only one quality is delivered by the system. This means that higher quality is provided than necessary. The difference in quality delivery and demand is called "quality surplus" (Agudelo-Vera et al., 2012).

The consumer side releases matter and energy after use. As described before, this outflow is often classified as waste but it has still a certain quality. This is called “un-used remaining quality" (Agudelo-Vera et al., 2012).

Linear metabolism

The energy and matter transformation described in the paragraphs before represents a linear metabolism which is often found in the urban fabric (Broto et al., 2012). To satisfy the demand, hinterlands and other cities must continuously supply urban areas in order to meet the demand (Rovers, 2007). Water and electricity are only two examples of such matter and energy (Baynes, 2009). The supply of too high quality and disposal of remaining energy as waste is one reason for unsustainable resource use in cities. The exhaustion of heat energy into the environment or nutrients in waste water for example are such losses.

2.1.2 UHA and strategies

Increasing urbanization will likely increase the demand for more resources on the one hand and increase the output of waste on the other hand (Rode, 2010). However, this output can also be seen as secondary resources and might be used to meet demands which do not need the high quality of the distribution network. The stop of this linear resources use can open new chances to cities. The focus on natural resources in traditional resource management does often hide the approach of seeing waste as secondary resources. Grey water or residual heat energy have still a considerable amount of quality that can be used. This point of view can contribute towards the third energy landscape: the city as producer and supplier of resources and user of waste through a closer connection of energy systems and physical landscapes (Noorman and de Roo, 2011).

The concept of seeing waste as secondary resources changes the view on urban metabolism. Instead of following a linear metabolism, the aim of urban harvesting is to develop strategies to use resources effectively and efficiently (Rovers, 2007). This can happen through the closure of gaps in the distribution and use of resources. Meeting the demand through careful consideration of the actual need of quality and investigation of remaining quality in the system can create linkages (Leduc et al., 2009).

The analysis therefore considers two main actors: supplier and consumer. In urban harvesting a consumer can also become a producer of secondary resources. The interaction between these actors are the starting point of the energy system analysis.

According to Agudelo-Vera et al. (2012), urban harvesting consists of four steps:

- 1. Inventory of demand
- 2. Options to minimize demand
- 3. Inventory of alternative sources
- 4. Harvest local and residual resources, connect source and demand

The first step in such an approach can be the exploration of the demand of the consumers, followed by considerations on how to minimize this demand. The third step is to think about alternative resources to fulfill this demand. In an UHA also consumers can become producers of secondary resources. In the final fourth step supply and demand must be coupled. The urban harvesting approach of local and renewable resources as secondary resources can next to other renewable resources play an important role.

2.2 Thermodynamics and heat energy

In order to get a deeper understanding of heat energy, principles of thermodynamics are introduced in the following paragraphs.

2.2.1 Thermodynamic principles

Thermodynamics is the science of general energy. It deals with different forms of energy, matter and its conversion. Energy transformation and characteristics of matter are closely linked. There is almost no physical process without energy transformation. Central to thermodynamics are three physical principles:

- conservation of mass
- conservation of energy (First thermodynamic law)
- limited possibilities to transform energy forms into each other, for example heat energy into work (Second thermodynamic law) (Peter et al., 1998).

2.2.2 Thermodynamic systems

A thermodynamic system is the object in which thermodynamic properties should be examined. The analysis can for example focus on gas or water and its energy and matter transformation in a system like coal power plants. The thermodynamic system is separated from the environment by a system border. It is not a physical border but a theoretical boundary to the environment. This border can change during the examination and can also be permeable to energy and matter. The boundary conditions are chosen for each analysis and can, if chosen well, simplify an analysis significantly (Peter et al., 1998).

In thermodynamic analysis three different boundary conditions are used:

- open,
- closed and
- isolated systems.

In open systems, energy and matter can pass in and out of the system boundary. In closed systems, energy can pass through the system boundary but not matter. In isolated systems, both matter and energy are isolated from the environment and there is no transfer between inside and outside of the system boundary (Atkins and Paula, 2010).

2.2.3 Thermodynamic laws

Thermodynamics as science of general energy is based on some basic thermodynamic laws. For the purpose of this work the first and second law of thermodynamics are of special interest. The first law of thermodynamics describes the physical phenomenon that energy can neither be created nor destroyed in transformation processes. The second law of thermodynamics limits the transformation between different energies. It introduces the principles of exergy and entropy. Exergy can be used to indicate the maximum amount of work that can be used (work capacity) and will be discussed later more in detail. Entropy on the other hand is used to explain why energy cannot be transformed limitless to other energy forms. The principle introduces terms like reversible and non-reversible processes.

First law of thermodynamics

The first law of thermodynamics can be described as law of conservation. According to it, energy can neither be created nor destroyed. It can only be transformed between different states. Most available energy on earth is a result of the sun. More than 99 % of the energy available on earth is the outcome of solar radiation. It was transformed in different processes to other energy forms (Stremke et al., 2011).

Second law of thermodynamics

The second law of thermodynamics makes statements about the limited possibility to transform energy from one state to another. It introduces the term of entropy which is often wrongly explained as a measurement for order respectively disorder (Lambert, 2002). Entropy can, however, be used to determine how much work can be done with a certain amount of energy.

Most energetic processes on earth create some sort of entropy and are therefore not reversible. This limits the possibility to transform energy into each other infinitely (Peter et al., 1998). This means that the energy quantity, which is possible to use for work, is decreasing. On the other handy, entropy increases. Some authors use the terms like 'useful' and 'less useful' energy to distinguish between energy that can perform work and that cannot (Stremke et al., 2011). Terms like 'less useful' might apply within a certain system boundary but can on other hand mislead to the assumption that some energy cannot be used at all. A factory for example is producing large amounts of heat energy as a result of burning coal. In this process entropy increases. Within this factory the heat energy cannot be used further and might be therefore declared 'less useful'. However, next to the factory could be residential houses whose owners also burn coal. Though, they need this energy for heating the houses. Increasing the system boundary from the factory building to neighborhood gives planers the possibility to see energetic potentials. The generated heat energy from the factory can then be used for heating the houses. In effective and efficient urban metabolisms waste heat energy can be one of the remaining qualities which might be used in urban harvesting. Such an approach was for example demonstrated in urban areas in the Netherlands by Leduc and Van Kann (2013).

'Second-law thinking' has already been adopted into some disciples. These are for example building engineering, architecture and urban planning. 'Second-law thinking' is however not well embedded into spatial planning. This is quite unsatisfying because entropy and exergy concepts can play an important role towards sustainable planning. Including 'second-law thinking' into planning has the high potential to increase efficiency in energy transformation. Inspiration from natural ecosystems which generally do not produce waste can help to design closed cycles that use waste as renewable energy (Stremke et al., 2011).

Exergy

In order to introduce exergy thinking as concept into spatial planning, a deeper understanding of this term and its principles is necessary. In the following some variables, which can assist planners, should be developed.

Exergy gives information about the maximum amount of work that can be performed with a given amount of heat energy or energy "when in equilibrium with a reference or the surrounding environment" (Leduc and Van Kann, 2013; Dincer, 2000). The work capacity therefore "depends on the difference between the state of the carrier and its environment" (Stremke et al., 2011). The difference in energy level is also called gradient and can be calculated for thermal, electrical and potential exergy.

In urban contexts, work capacities exist at various levels, scales and places. Surface water for example can be a source of heat energy in spatial planning (Shukuya, 2009). This energy always needs an energy sink to be in equilibrium with in order to perform work (Hepbasli, 2008).

Energy can only be a potential if it is at the place where it is needed. Otherwise energy needs a mode of transportation in order to reach the place where it is needed. Sufficient infrastructure must be therefore ensured. A source of energy might also not perform the same amount of exergy at all times. As work capacity depends on an exchange between the system and the environment, periodicity is crucial if the environmental circumstances can change through time (Stremke and Koh, 2010). In winter for example the temperature difference between a constant source of hot water with the same temperature all year and the environment is higher than in summer. The work capacity increases therefore in winter (Stremke et al., 2011).

Stremke et al. (2011) therefore mentioned following points that are important to describe the working performance of energy:

- the source
- the system environment
- the energy sink
- the energy infrastructure
- periodicity.

2.2.4 Water, exergy and heat energy recovery

Water occurs on earth in three different forms: ice, liquid and gas. It is often not pure but contains as a resource water, nutrients and energy. Frijns et al. (2013) describes three main aspects which have the highest potential in terms of using water as resource:

- organic carbon
- heat energy
- underground thermal energy

Organic carbon

Wastewater in the urban system contains high amounts of organic matter and nutrients (Frijns et al., 2013). These organic matters and nutrients were long time seen as a problem which has to be dealt with. The uncontrolled discharge of sewage into Lake Constance in in the 1960s for example almost led to an ecological collapse of the lake. The introduction of sewage plants in the following years prevented the lake to become a dead zone. The quality increased so far that since 1998 the water has been sold as high quality drinking water (Blatter, 2001). However, the aim treatment of the sewage was to get rid of the problem instead of seeing it as resource. "There is a growing recognition within the water sector that an environmentally, economically and socially sustainable sanitation system requires sewage to be viewed as a set of resources to be recovered, recycled and reused (water, energy, nutrients) rather than a waste product to be treated to successively higher standards before release to the environment" (Mitchell et al., 2012).

Seeing sewage as a resource can increase energetic recovery. Currently, waste water treatment needs high amount of energy, e.g. in the activated sludge treatment (Frijns et al., 2013). Wastewater can, however, be a source of energy, e.g. biogas. The anaerobic digestion of sludge produces biogas which can be used for electricity and heat energy recovery (Elías-Maxil et al., 2014).

For the purpose of compactness of this work, the study mainly focus on heat energy and how to close cycles there. This does, however, not exclude the combination with other cycles like phosphorus in practice.

Heat energy recovery and storage

Water has not only the physical ability to change its state and thereby absorb energy from the environment. It can also store high amount of energy per volume. The thermal capacity of water per volume-unit and Kelvin is three times higher than of many soils (Manteghi and Remaz, 2015). This also means that much more heat energy is required to rise the temperature of water per kg. In comparison to air, four times of energy has to be added to rise 1 kg of water for 1 Kelvin (Porges, 2001).

The high thermal capacity might be desired for cooling or storing heat energy but leads to high energy demand if hot water is needed. In the US about 13 % of the total residential energy consumption is used for heating water (Sanders and Webber, 2015). This does not include space heating. In the Netherlands houses loose about 40 % of their energy through wastewater (Hofman et al., 2011).

Hot water is needed for many purposes like bathing, cooking and laundry. In the Netherlands residual water heating is accountable for about 23 % of the household's gas consumption (Elías-Maxil et al., 2014).

Spatial planners have several options at different spatial scales when they want to recover heat energy. Heat energy recovery within buildings, neighborhoods or central at a waste water treatment plant is for example possible.

In buildings a recovery of heat energy is directly possible after use. The benefit from direct harvesting of wastewater is that the temperature is higher than for example in the sewage system. Water therefore only needs a low temperature lift to reach sufficient high temperature for use. With the combination of a heat energy exchanger and heat pump a direct recovery of heat energy is possible which then can supply a shower with hot water. This concept was developed by Meggers and Leibundgut (2011) who made research on low exergy building systems.

Decentral heat energy recovery in buildings has the disadvantage that every house needs an own heat pump and might therefore depend on the willingness of the house owners. Central collection in the sewerage therefore might be easier to organize because only one company has to install heat exchangers into the system. The heat energy exchange is generally possible at two locations: in the sewer systems or after treatment in the waste water treatment plant (Mikkonen et al., 2013). The first one was done in Zurich and Hamburg for residential areas. Heat energy exchange in the sewer system has however the disadvantage that in case of too much heat energy extraction the water becomes too cold for the waste water treatment plant (Frijns et al., 2013).

Heat energy exchange after the treatment process is done in Hammarbyverket, Stockholm. It is the largest of its kind worldwide and can heat 95 000 residential buildings, producing 1235 GWh of heat energy annually. The plant furthermore produces cooling energy and electricity from hot steam in order to increase efficiency (Mikkonen et al., 2013).

Heat energy recovery from surface and drinking water

Heat energy can be recovered from different water bodies. Among these are drinking water systems, lakes, rivers, oceans, fishponds, reservoirs, canals and streams (Manteghi and Remaz, 2015).

In the following some examples of how heat energy can be extracted and stored in water bodies are mentioned. In Almere, the Netherlands, a cost benefit analysis has been done for a neighborhood which analyzed if heat energy can be extracted from the freshwater system. It resulted that 900 homes could be heated. The analysis was based on an extraction of heat energy at the water plant. As temperature is reduced at the water plant, the water temperature reaching the houses is also lower. However, the temperature difference with and without heat energy exchange is at the homes much lower than at the water plant. The reason is that the soil in which the pipes lay is in constant heat energy exchange with the water. The water temperature at the homes is therefore only slightly lower than without heat energy exchange. To heat the water to the temperature level without exchange, an energy input to an equivalent of heating 85 homes is needed (Blokker et al., 2013).

Underground heat energy storage

Storage of heat energy is also of special interest for spatial planners. Temperatures in cities vary within a year. This does however not count for soil below a depth of 10–15 m where temperature throughout the year is nearly constant. While cooling of buildings might be needed in summer, heating is more important in winter. Storing heat energy underground is one option to bridge the annual needs. Underground heat energy storages (UTES) are for example already applied in the Netherlands. Thermal energy can be stored and delivered for cooling of buildings and space heating (Lee, 2013).

Formally there is a distinction between open ATES (aquifer) and closed BTES (borehole) thermal energy storage systems. A combination with heat energy from other sources like surface water, tap water or sewer systems is possible (Frijns et al., 2013). Miltenburg (2008) explored the use of ATES in an urban district with 2816 houses of the Dutch municipality of Hugowaar. They combined the ATES with heat energy extraction from surface water in summer and managed to recover enough heat energy to satisfy the district's demand in winter.

Some challenges are "interfering systems, leakage of energy in the groundwater body and difficulties in retaining the cold/heat balance" (Frijns et al., 2013) which can slow down the construction of UTES. A good understanding of groundwater is also necessary in order to minimize risks and conflicts with drinking water extraction.

2.3 Urban water use and sustainable water management

Like other urban processes, the urban water use is characterized by linear processes. Tap water is taken from rivers or groundwater and is after use and treatment discharged into the environment. Several scientists claimed that this conventional urban water management is not sustainable and not a model for the future (Marlow et al., 2013). One reason for this linear approach and little multifunctional use of water resources is the traditional categorization and limitation of water to one special function: e.g. tap water, sewerage or floodwater (Bach et al., 2014). The linear view on certain functions resulted in the creation of both separate infrastructure and service providers (Brown, 2008). This physically and institutional separation "led to philosophical compartmentalisation and shaped perceptions of system boundaries over time" (Wong and Brown, 2009).

However, the water system delivered until now its promised services like water supply or public health. This leaded to an "unwillingness to acknowledge and improve our limited understanding of feedbacks, non-linearity and time delays" (Bach et al., 2014) that could influence and change the system's state (Pahl-Wostl, 2007). "In the past, water managers have often reduced this complexity by focusing on optimizing singular parts of the water cycle such as 'supply security' in isolation and/or in absence of reliable consideration to the other dimensions of the cycle." (Wong and Brown, 2009)

However, this approach of single-object optimization proved to be less and less successful (Erbe and Schütze, 2005).

Bach et al. (2014) therefore suggests an integrated urban water management that:
"• considers all parts, components, of the system
• involves water conservation and diverse fit-for purpose water supplies,
• works at a range of scales (both central and decentralized) and
• allows establishment of links with other environmental cycles".

This approach, however, must still guarantee all the benefits and services which the urban water cycle offers: "supply security, public health protection, flood protection, waterway health protection, amenity and recreation, greenhouse neutrality, economic vitality, intra and inter-generational equity; and demonstrable long-term environmental sustainability" (Wong and Brown, 2009). These multi-benefits of water require the planner to acknowledge urban water as complicated issue which needs careful investigation. Planning approaches should furthermore follow the idea that plans strengthen and support more than one benefit and service of water.

2.4 Spatial planning, scales and networks

Spatial planning is, as the term 'spatial' implies, about planning areas on a spatial scale bigger than single entities. Spatial planners can have different perspectives and scales while creating plans. In the following some scales from literature are mentioned: Roggema (2013) distinguishes between region, city, neighborhood and buildings as a geographic approach on which planning projects take place. Within these areas further distinctions between urban functions are possible. These can be for example built-up areas like "residential areas, industrial/business parks, area for leisure activities, and transport area and non-built-up areas, such as agricultural area, forest area and water bodies" (Leduc and Van Kann, 2013).

From an energy perspective on spatial planning, like it is followed in this study, a division between spatial scales might be also possible. The chapter 2.2 indicated that a change of perspective from building scales to a higher scale might open chances for energy reuse and energetic linkages.

Looking at the energy network, scales become explicit. The electricity network is a system that connects different urban functions. It was for centuries a highly centralized system (Sioshansi, 2011). This started to change in the last 10-20 years and in recent years the discussion about smart grids started. The term relates to the challenges that the electricity network is facing. Electricity was produced a long time with fossil fuels, nuclear power, hydro power and others by central power plants and companies (Farhangi, 2010). With the spreading of renewable energies like solar panels, some former consumers and functions outside of the traditional production industry became electricity producers (Lund et al., 2012). The centralized system is as a result in the process of transforming towards decentralization. This decentralization causes difficulties in maintaining a constant electricity supply (Kanchev et al., 2011).

Renewable energies like solar energy are more dependent on weather conditions than other electric power sources which are for example based on fossil fuels. Changing weather conditions causes changing production of electricity. The results are fluctuations in the grid. The aim of a smart grid is to make the grid stable by steering the production, consumption and buffers. This should ensure that electricity supply is ensured efficiently and reliably at all time (Li et al., 2010). However, not only the network structure is changing. From an institutional point of view, these changes also mean an increasing institutional fragmentation. Electricity producer, supplier, grid owner and consumer are not clearly separable any more (Szulecki and Westphal, 2014).

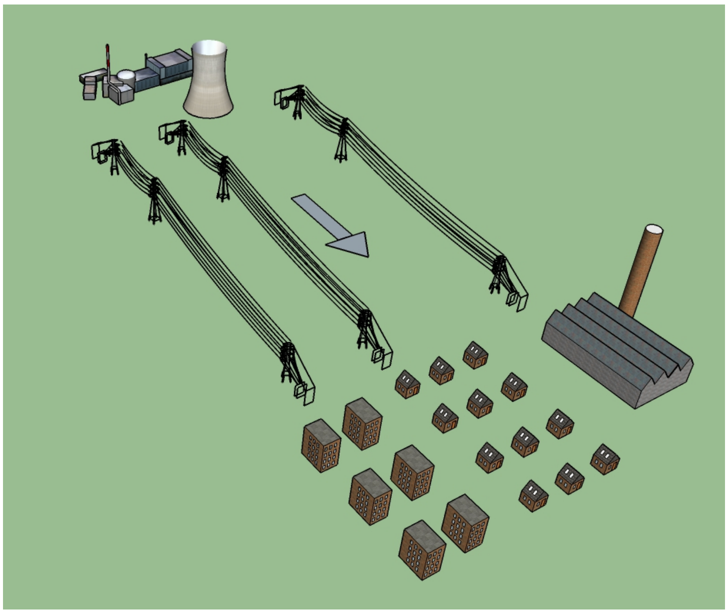

FIGURE 2.1: Central grid

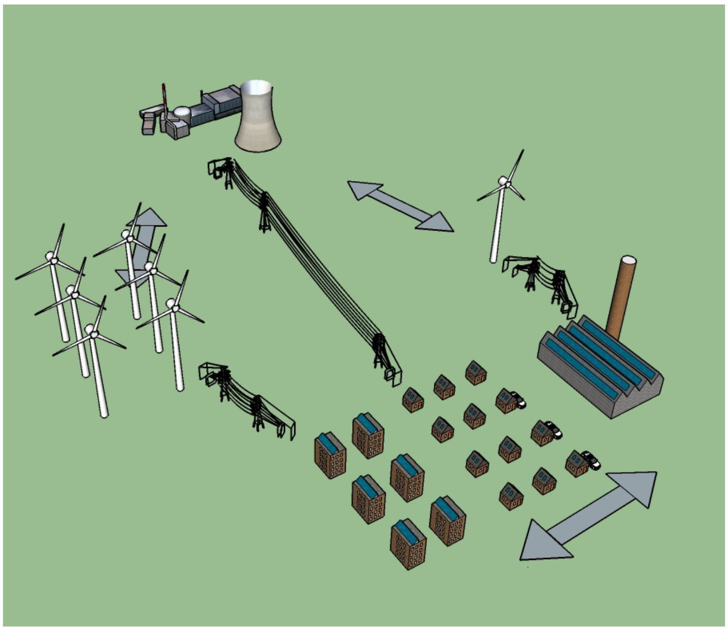

FIGURE 2.2: Smart grid

A comparison with the heat energy system reveals that it has also been very centralized. The difference to electricity supply is that there is no heat energy grid in terms like the electricity grid. Exceptions are district heating systems that cannot be found everywhere. In most cases the heat energy supply is coupled with fossil fuels like gas, coal and oil that gets transported from a central point to urban functions. The production of heat energy is done on building scale, but the provision with resources is ensured by a centralized system (Stremke and Koh, 2010).

Urban functions are not connected to each other in a way that heat energy could be exchanged. So far, no coordination of the use and production of heat energy is undertaken between urban functions. One reason might be that there has never been only one source for heat energy and that therefore not one distribution network has existed (Persson and Werner, 2011).

To produce heat energy, mainly chemical matters are transformed through burning on building scale. Electricity on the other hand was produced in the past outside the building in power plants. Smart grids change the supply structure by facilitating each building to function as producer of electricity. This energy can be distributed by the grid. Heat energy that gets produced, however, has no grid to get distributed.

Urban functions are connected in the urban fabric to several infrastructures: electricity,

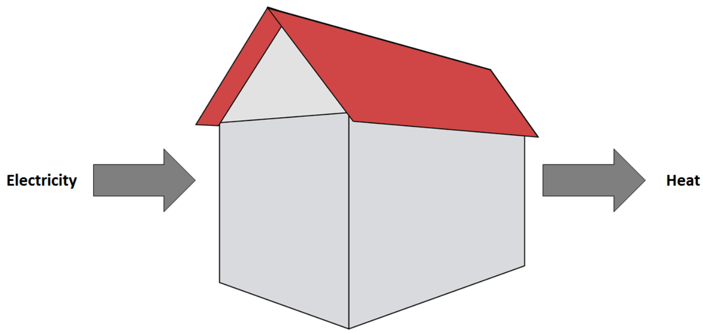

FIGURE 2.3: Urban electricity use: Electricity gets transformed into other modes of energy like heat energy

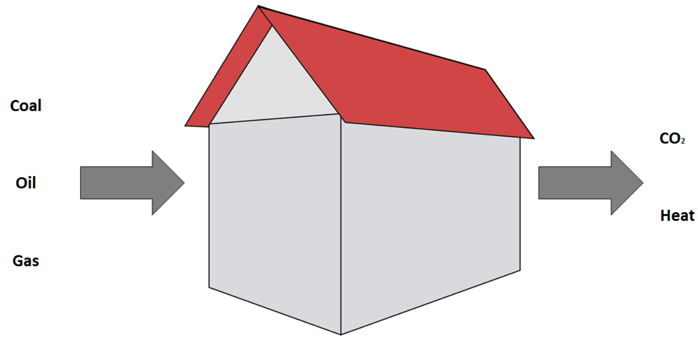

FIGURE 2.4: Urban heat energy use: heat energy as product of energy transformation

fresh water, wastewater, streets and in some cases gas (Vliet, 2012) As discussed in chapter 2.2.4, water bodies like wastewater, freshwater, lakes or underground aquifers have the potential to function as source of heat energy. Water infrastructure, like the electricity grid, connects all spatial functions (Kenway et al., 2011). It therefore establishes a spatial connection between producers and consumers (Gandy, 2004).

However, there are some physical differences between the electricity grid and water system on how they connect urban functions. These differences are based on the mode of transport of electricity and water. Electricity gets transported through conductors. Different electric potentials and charges determine the usable potential energy (Bansal, 2006). Water gets transported through pipes (Gandy, 2004). Its flow is dependent on gravity and pressure (fresh water). The physical property of water makes it further possible to store heat energy even if it is not flowing. The reason is that water is only a mean of transport for heat energy and not the potential itself (see chapter 2.2.4, heat capacity). Electricity on the other hand gets its potential from electric charge differences. The result is that water and its heat energy can be stored while electricity needs to get transformed into other modes like chemical energy in batteries (Crabtree and Lewis, 2007).

Chapter 3

Method

3.1 Conceptual framework

This chapter is aimed to describe the research methodology of this study. The purpose of this study was to develop an approach for spatial planning that can help to harvest and use residual heat energy potentials from urban water bodies. The approach is based on theory of urban spatial planning and should be used for identifying functions, potentials and uses of different urban waters like lakes, rivers and sewage systems in order to create sustainable HESs. One aspect in this approach is identifying and drawing linkages between heat energy potentials and usages of water in urban areas. The study is meant to give recommendations for future energy conscious planning. Of special interests were during the development of the approach variables which are relevant for assessing uses of various types of waters for sustainable HESs. The approach has been illustrated and presented with a real case study.

The literature review on urban metabolism revealed that in spatial planning energy and water flows are often considered linearly from resource mining over consumption and waste production to waste treatment. To understand and characterize matter and energy flows, the following variables are accordingly to the theory on subchapter 2.1 and especially the work of Stremke et al. (2011), Leduc et al. (2009) and Agudelo-Vera et al. (2012) central in order to describe HESs: quality, quantity, spatial scales in combination with energy networks, periodicity and thermodynamic laws. These variables are elaborated further in this study in order to break through linear resource consumption towards effective and efficient systems.

Mining, consumption, waste production and waste treatment are connected to different urban functions that use and transform matter or energy. The input into one function is characterized by matter or energy with certain **quantity** and **quality**. The mechanisms that use the matter or energy at each function transforms the quantity and quality into matter and energy which cannot be used at this function anymore but still has remaining quality. Harvesting remaining quality can be a way to minimize waste and can take place at different **spatial scales**. This can lead to matter exchange between functions within the urban fabric. Throughout the year heat energy demand and availability of water and heat energy changes so that **periodicity** was considered in the study. Furthermore, **thermodynamic laws** gave references on how heat energy can be harvested and used. These variables were used to create heat energy linkages between urban functions in a multi-step approach. This approach can be used in spatial planning in order to harvest heat energy in urban areas and water bodies.

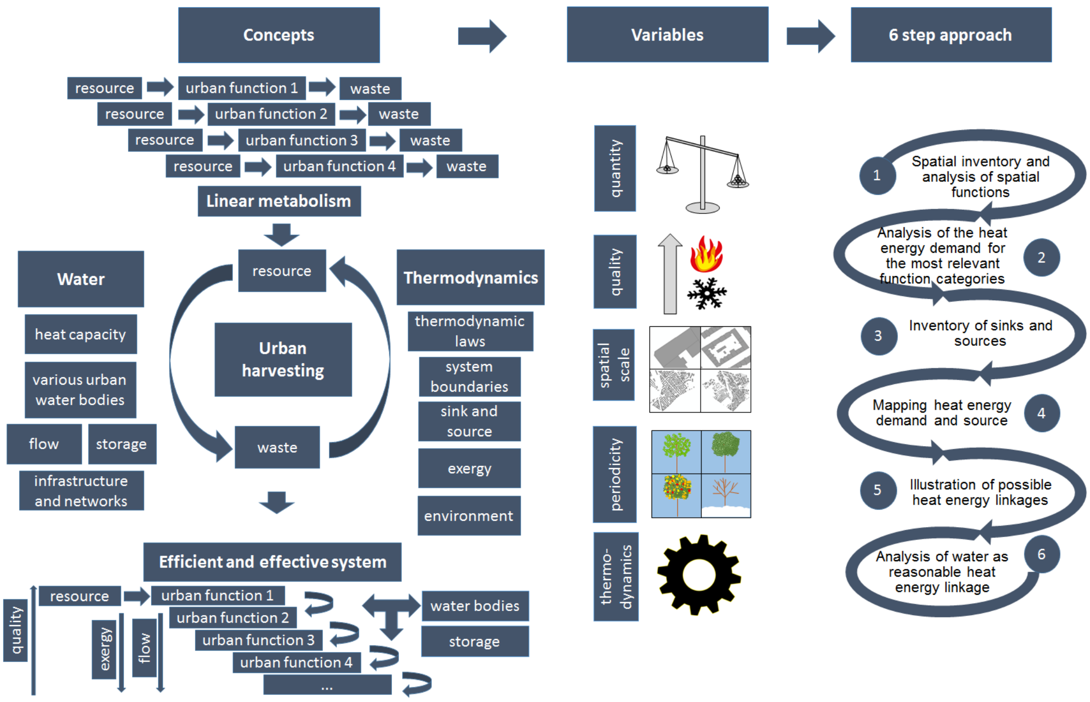

FIGURE 3.1: Conceptual model of this study

Urban functions are dependent on energy and matter exchange between each other. Energy and matter like electricity, water and gas are usually not provided by one single urban function. While residential or office buildings consume matter and energy, other functions produce them (see chapter 2.1.1). This dependence on each other and the location of all urban functions, which is different for all cities, characterize the urban fabric of a place. To take dependence and exchange into account, the analysis in this study is conducted on a system and geographic scale bigger than single urban functions. In such an analysis cities are seen like an organism in which energy and matter is transformed and transported in circular systems. In order to function as an organism, the spatial scale in this study was chosen big enough that dependencies and the variables quality, quantity, spatial scales in combination with energy networks, periodicity and thermodynamic thinking could be taken into account.

The underlying philosophical position of this study is, as argued in subchapter 2.1.2 and 2.2.3, that urban planning should be more focused on energy conscious planning. As explained in chapter 2.1, current spatial planning does not consider energy supply and use much in order to design the urban fabric. Furthermore, 'second law thinking' is not disseminated yet. This study proposes that energy should have more attention in spatial planning and therefore influences the way of planning. It argues that spatial planning can help to develop strategies to develop sustainable HESs.

For the purpose of developing strategies, the study proposes a methodology consisting of two parts to identify how spatial planning can be influenced:
1. theoretical six step approach to identify and link heat energy sources and sinks with special focus on water bodies, developed out of literature in chapter 2;
2. a case study including empirical data collection to illustrate and apply the conceptual usability of the six step approach.

3.2 Theoretical six step approach: The heat sensitive city approach (HSCA)

In this chapter the steps of the HSCA are introduced. The development of the approach is based on literature research of the findings of chapter 2. Ideas were derived from concepts like sustainable HESs, urban water use and infrastructure, thermodynamics, heat energy and energy networks. These findings were used to develop a spatial planning approach that can help to identify heat energy potentials in combination with water bodies, categorize these in connection to the variables quality, quantity and periodicity and link the potentials together with heat demand. Functions with heat energy demand are in this study sinks while functions with an excess of heat energy are sources. The reason to choose literature research as method is that it can help to sum up what is currently known in some disciplines and help to identify lines of argument that exists in connection to the issue (Lewis-Beck et al., 2004).

For the purpose of this study, the approach of Leduc and Van Kann (2013) on harvesting urban energy, sustainable urban development and the application of exergy was developed further. The approach of Leduc and Van Kann (2013) takes the idea of creating cycles, reuse of waste and thermodynamic thinking into account in order to create what they refer as productive urban regions. In these regions the principle of harvesting renewable and residual resources should be used in order to create effective and efficient systems. For the analysis in their study the authors conducted a spatial inventory to identity urban functions. The reason is that this distinction between functions also helps to identify resource consumption patterns which are later used to bring heat energy potentials and demands together.

The proposed approach in this study also takes spatial analysis including a visualization of urban functions on a map as starting point. The reason to choose spatial analysis and visualization as a first step is that visualization of functions supported its worthiness in the mentioned study of Leduc and Van Kann (2013) and also other publications like Knies (2015) which were meant to identify in spatial planning heat energy potentials and bring the potentials together with heat energy demand.

In order to conduct a spatial energetic analysis, the proposed approach in this study furthermore identifies heat energy demands of the urban functions. In order to identify potentials, the approach especially focuses on water bodies. The methodological choice to focus on water in this spatial planning approach has several reasons: water infrastructure is an inherent part of spatial planning; it is not considered much with the energy transition so far, although water is used in many heating processes; water has a high heat capacity which can be important to function as sink or source and it connects all urban functions.

The potentials and demands are mapped in the approach to illustrate their spatial distribution. This visualization should help to create energetic linkages between demand and sources of heat energy. Arrows are used to show possible connections of them. A further visualization with additional arrows are used to illustrate how existing water infrastructure can contribute to create reasonable energetic linkage between various urban functions. The difference between possible and reasonable connections is that possible energetic linkages illustrate potentials between heat energy demands and sources while reasonable energetic linkages use water bodies in order to create the connection.

The approach to find heat energy potentials and demands in an urban area, the methods of visualizing them on a map, illustrating flows, and showing heat energy potentials in an abstract way, resulted in the development of the HSCA that could be used in spatial planning practice. This approach is meant to take the idea of resource exchange between various urban functions and the analysis of these urban functions in order to create sustainable HESs into account. This approach introduces especially periodicity of heat energy potentials and the use of water bodies as means of transport for heat energy as new characteristics into spatial planning practice. The term means of transport for heat energy in this study refers to both heat energy potentials for heating and cooling.

The proposed six steps are:

1. Spatial inventory and analysis of spatial functions
2. Analysis of the heat energy demand for the most relevant function categories
3. Inventory of sinks and sources
4. Mapping heat energy demand and source
5. Illustration of possible heat energy linkages
6. Analysis of water as reasonable heat energy linkage

These steps are described more in detail in the following table 3.1.

TABLE 3.1: Heat sensitive city approach

1.	Spatial inventory and analysis of spatial functions	
	sub-point	purpose
a	distinguish between built-up, non-built-up, and water areas/ infrastructure	first distinction between functions that consume resources (built-up), consume no resources (non-built-up) and functions that might work as sink and source of heat energy
b	find built-up and water areas that are similar and can be classified, examples: residential, industry, open space like grass and parks, waste water, open water, fresh water and other infrastructure like streets	classification of urban functions into categories of similar properties should help to simplify energetic analysis
c	illustrate land-use on a map to give a quick spatial overview of the area	visualization should help to gain a quick overview of the studied area, making the identification of linkages spatially possible

2.	Analysis of the heat energy demand for the most relevant function categories	
	sub-point	purpose
a	classify heat energy supply and heat energy utilization according to temperature classification, e.g. low, medium, high	simplifies the analysis and increases transparency, introduces thermodynamic thinking
b	analyze heat energy demand for the classified functions (see step 1), categorize these into the classified temperatures (see step 2.a)	create a heat energy demand profile for all functions, illustrates that every function has different heat energy demand on quality and quantity
c	draw periodicity, e.g. day and night, seasons	heat energy demand may vary throughout the year

3	Inventory of sinks and sources	
	sub-point	purpose
a	make an inventory of the possible heat energy sinks and sources, e.g. water and air	qualitative prediction of heat energy sinks and sources
b	analyze how much heat energy can be extracted: quality, quantity and periodicity	evaluation of the heat energy potential

4	Mapping heat energy demand and source	
	sub-point	purpose
	illustrate the findings of step 2 and 3 on the map of step 1 with e.g. colors or scoring system	visualize heat energy demands and sources

5	Illustration of possible heat energy linkages	
	sub-point	purpose
	draw arrows between sources and demand of heat energy according to the variables quality, quantity and periodicity	illustration of possible heat energy flows between demand and source of heat energy

6	Analysis of water as reasonable heat energy linkage	
	sub-point	purpose
a	draw arrows in the flow direction of water bodies	illustration of water flow direction
b	compare theoretical potentials (demand and sources of heat energy from step 5) with flow direction and distribution of water bodies	find synergies between water flow direction and demand and source of heat energy
c	make recommendations for urban planning in order to bring flow direction and possible potentials together	showing potentials to create effective and efficient systems

3.3 Case study and empirical data collection for St. Johann

To illustrate and present the HSCA in this study, the method of using a case study was chosen. A case study was chosen because it allows to test hypothesis (Flyvbjerg, 2006). In particular a single case study was chosen. The reason is that the method of a single case allows to go deeper into research of a specific issue (Becker et al., 2012). The case chosen in this study was St. Johann, Basel. It was used to illustrate and present the HSCA and identify strengths and weaknesses of the approach. This chapter describes how data was collected in this study.

Empirical data for the showcasing of St. Johann, Basel, was collected through literature research and expert consultations. The data is presented through visualization of the case on maps, illustration of flows and heat energy potentials.

Because energy analysis is not connected to a specific location and can be done at any urban place and an analysis furthermore needs knowledge about the local circumstances, the case was chosen accordingly to GIS data availability, local knowledge of the author about the place, the existence of open water bodies and a mixture of different urban functions. The reasons for a variety of urban functions is based on the methodological approach of this study to connect urban functions and create effective and efficient systems.

For selecting the case, at first cities with open water bodies like Karlsruhe, Bremen, Rotterdam, Düsseldorf and Basel were searched. Basel was finally chosen as city because GIS data were freely available online and local knowledge about the area existed. The district of St. Johann was chosen in particular because it is characterized by industrial, recreational and residential areas. In particular several functions like two hospitals, three power plants, and water infrastructure including the river Rhine were found in this area. It was assumed during case selection that having this variety of functions can help to identify different characteristics for a high diversity of urban functions. This should help to identify a variety of possible and reasonable energetic linkages.

The case of St. Johann, Basel

The district of St. Johann is located in the northeast of Basel. It shares borders with France in the north. In 2015 18958 inhabitants lived on 225,4 hectare (Statistisches Amt, 2015). The urban fabric is characterized by 3 to 5-story residential buildings in the south and industry in the north. The headquarter of the Bell Food group, according to its own description one of the leading meat processor in Switzerland and Europe and other meat processing industries are located there. Several office buildings of smaller companies can be found. The newly designed Novartis Campus on a former chemical production site is located in the north next to the river Rhine. Two hospitals and a park can be found on the north-west. St. Johann is also a major producer of electricity and heat energy with having three power plants on its area: an incineration plant, a wood fueled power plant and the heat power plant Volta. All three support the district heating system with temperatures of 170-190° C and 850 GWh/a. It is planned to reduce temperature to 120° C in a first step and finally to about 75° C in future.

3.4 Methods for case study and empirical data collection

Different methods were used to get data in order to illustrate the approach for the district of St. Johann. A short summary of the methods can be found in table 3.2.

TABLE 3.2: Methods for case study of HSCA

No.	Step	short description	methods
1	Spatial inventory	distinguish between urban functions	GIS data, Google street view, contacting experts
2	Heat energy demand	find heat energy demand for relevant functions	document analysis, contacting experts, MS Excel
3	Sinks and sources	inventory of water bodies	document analysis, contacting experts of the companies to obtain data (e.g. wastewater system), MS Excel
4	Mapping	visualizing potentials on a map	Scoring system, Illustrator
5	Illustrating theoretical energetic linkages	draw arrows	Illustrator
6	Analyzing water as mean of heat energy transport	compare flow direction of water and energetic arrows	Illustrator

3.4.1 Evaluation Methods

Scoring system

A qualitative scoring system was introduced as method to evaluate quantitative heat energy potentials. The reason to choose a qualitative scoring system was to create a limited number of categories out of a higher number of energy profiles. The aim was to simplify the visualization of demands and sources of heat energy in order to present information rich data in an aggregated way. This should help to identify high potential at first glance. For the purpose of this study the ranking consists of a 7-point scale with the following grading: +++, ++, +, 0, -, - -, and - - -. A 5-point scale would have increased aggregation but information would have been lost. A distinction between high potentials (+++/- - -), average potentials (++,- -) and low potentials (+,-) would not have been possible any more. More than 7-points would have decreased aggregation but increased information richness which would have resulted in a reduction of visual clarity. The classification of heat energy potentials was subjective and is not linear or logarithmic. The reason is that the classification is oriented accordingly to the seven main heat energy potentials of the urban function categorizations that could be found. This should make the grading more flexible and should ensure the clear visualization of case specific potentials.

Illustrator

Adobe Illustrator was used to visualize heat energy potentials, demands and sources. The findings from the scoring system, flow direction of waters and energetic linkages were illustrated on a map. The calculated heat energy demands and sources of heat energy were visualized with the 7-point scale of the scoring system. Boundaries were drawn around categories of urban functions to show functions of the same category. These boundaries were colored if either warmer waste water as a result of higher hot tap water demands (60° C), e.g. for hospitals or meat processors, or if the cooling and heating potential was expected to be comparable high in quantity, e.g. rivers with high flow rate and residential areas with low hot tap water demands (60° C). Furthermore, possible heat energy sources from cooling devices or computers were indicated with dots. No values were calculated or estimated for heat energy that is not connected with water. Therefore, dots were used in order to illustrate these heat energy sources.

MS Excel

Microsoft Excel was used to calculate the heat energy demands and sources including the heating load in this study. An Excel sheet was designed in which the equations used in this study were inserted. These sheets were created for the purpose of automating the calculations. The results were manually transferred into tables and inserted into the figures with Illustrator. No automated connection between Excel and GIS analysis through the ModelBuilder of ArcMap was established.

3.4.2 Data collection

Data were collected through different methods: internet document analysis, document analysis and expert contacting to obtain data. Therefore, maps of Basel, information about heat energy demand and heat energy production of urban functions in Basel and software to visualize the findings were used. Where no exact data were available, estimations were undertaken.

Documents

Documents were collected in order to characterize urban functions. These documents were used to identify heat energy demands or the possibility to function as heat energy source. An overview of the used documents can be found in the Appendix. At first data for every specific function category that was found in the case was collected. This data was used in order to characterize the heat energy characteristics of an urban category: quality, quantity and periodicity. This data included for example brochures of the network owning company. Where no data for a specific category in the case was available, generic data were used. These included empirical data from other studies and GIS analysis of areas. Empirical heat energy demands are one example of this kind of data.

Map

The spatial inventory is based on GIS data from the Geodaten-Shop of the Land Registry and Commercial Registry Basel-Stadt (Grundbuch- und Vermessungsamt, Kanton Basel-Stadt). Esri ArcMap 10.3 was used to create the map. Functions were classified according to the GIS data (attribute table, resolution per building) and building heights of residential areas were analyzed with Google street view. The map of St. Johann was created with the layers for the district boundaries of Basel and the official cadastral survey (DM01AVBS06D). A distinction between built-up, industry areas, rivers, infrastructure (not water related) and green space was derived from the available attribute table of the GIS data (Vermessungsamt, 2016). GIS analysis was furthermore used to estimate surface areas of urban functions.

Heat energy demand

No exact data of the heat energy consumption for urban functions were available for Basel. The values in this study are therefore taken from empirical data of Blesl et al. (2009). This data is based on estimating the specific heat energy demand in $kWh/(m^2a)$ through building types, buildings heights, function and building age. This method was chosen because buildings have similar characteristics related to building age and building material. The average data do not show the real situation for one building in Basel. However, with increasing number of buildings the derivation between average numbers and real values are becoming smaller (Blesl et al., 2009). Data for estimating the heat energy demand of nurseries were collected from BDEW (2009) and data for the meat processors from Schwarz and Heiss (1932) and Swissweg (2009). Values for hospitals were taken from EnergieAgentur.NRW (2010)

The specific heat energy demand of the urban function was multiplied with the area of this category. This area was based either on information material or on GIS analysis. The findings were an estimation of the whole area that was covered by one urban function category. These values were multiplied by the numbers of stories. The results were estimated heat energy demands (kWh/a) for every urban function and year in St. Johann, Basel.

The heating demand for drinking water and showering was estimated by values of the energy saving regulations of Germany 2003, the Austrian norm ÖNORM B8135 and guidelines (Metzger, 2010; Normungsinstitut, 1980). The heating demand for hospitals was assumed with water use values from EnergieAgentur.NRW (2010).

The values of the heat energy demand were then used to calculate the heating load. The heating load indicates the heat energy supply which is needed in order to maintain comfortable room temperature. Estimations were calculated accordingly the formula of Guideline Series VDI 2067 page 2 out of the yearly heat energy demand (VDI, 1993).

$$\dot{Q}_{N,building} = Q_{demand}/(f_v b_{VH}) \tag{3.1}$$

$\dot{Q}_{N,building}$: norm heating load (kW)

Q_{demand}: heat energy demand (kWh/a)

f_v: conversation factor (dependent on location in Germany)

b_{VH}: hours of full utilization per annum (h/a)

It was assumed that the heating load is half in spring and autumn and zero in summer for space heating. Heating loads for freshwater heating was assumed constant in this study throughout the year.

Heat energy source

Basel is located next to the river Rhine and has a sewage and freshwater system. Information about the flow and temperature of the river Rhine were taken from the Swiss Federal Office for the Environment, Section Hydrology (BAFU, 2016a; BAFU, 2016b). Data from measuring stations within the boundaries of Basel where either old or not updated regularly. The data taken in this study was therefore taken from other stations where updates were carried out on daily basis. The flow was measured at the measuring station in Rheinfelden, which is located about 20 kilometers upstream of Basel and the temperature was measured at the Palmrheinbrücke in Weil am Rhein (Germany), which is about 1 km downstream of Basel. Information about the freshwater and wastewater system were derived from plans and information brochures of the network owning company. The Construction and Transport Department of the Kanton Basel-Stadt is responsible for the sewage system (Basel-Stadt, 2016). A plan of the sewage system was provided on request as PDF file via email. Additional information about the water flow rate was provided at selected points. These were located at main sewers entering, leaving and within St. Johann. It was not allowed to publish the file with the sewage system in this study. However, the plan was used in the process of conducting this research and a simplified scheme is illustrated in figure 4.2. The freshwater system is owned by the IWB, which is an independent company owned by the Kanton Basel-Stadt. The map of the system was freely available from the internet (IWB, 2015).

3.4.3 Calculations of heat energy potentials

Water has, compared to air, a relatively high heat capacity. To calculate the flow of heat energy that can be drawn from water the following thermodynamic equation was used:

$$\dot{Q} = \dot{V} * \rho * C_p * \Delta T \tag{3.2}$$

(Peter et al., 1998)

$\dot{Q}$ = rate of heat energy flow ($kJ/s, kW$)

$\dot{V}$ = water flow (m^3/s)

ρ = density of fluid water at temperature T (kg/m^3)

C_p = heat capacity at temperature T ($kJ/(kgK)$)

ΔT = temperature difference between entering and exiting the heat pump (K)

This equation was used for all water bodies. It is assumed in this study that water is the main component of all water related streams. Possible pollutants which might influence the heat capacity were not taken into account. The density and heat capacity can be seen as relatively constant in the examined low temperature range ($\rho = 1000\ kg/m^3$ and $c_p = 4,2\ kJ/(kgK)$). The difference between the water temperature before and after heat energy extraction or heat energy addition is defined as temperature difference (Peter et al., 1998).

3.5 Approach for case study

The proposed HSCA uses an inventory of urban functions as starting point. Urban areas were distinguished between built-up, non-built-up and water areas/ infrastructure. It is possible to classify these areas into many different categories. The approach used in this study especially focuses on a distinction of functions in built-up areas and water bodies. Non-built up areas were not further categorized. Different types of parks, forests and infrastructure like streets, underground or parking lots could be classified. However, these non-built-up areas were not the focus of this study because they do not directly influence the water and heat energy infrastructure. Built-up areas and water bodies were on the other hand specified more deeply because each function has different resource consumption and waste production patterns. The classified functions are only examples and can be selected for each cases individually. The aim of the case analysis in this study was to show how functions can be analyzed and served as illustration of the approach. It was not possible in this study to name all functions which are valid for any cases. Planners using this approach are therefore invited to add and change classifications according to the needs of their case (e.g. schools, swimming pools etc.).

In the case study residential houses were one classified category of the analyzed urban function. The literature review resulted that residential houses mainly need two different water temperatures. Therefore, two temperature categories for residential houses were chosen in this study. One further category was made for industrial processes. More classifications would be possible for analysis which focus for example in particular on industrial areas.

In summary, the three temperature categories are:

1. Showering, washing dishes or cooking are actions where water gets in direct contact with humans. Water therefore needs to be safe for use. To ensure low bacteria concentration the water must have a certain temperature. 60° C hot tap water was used as one category.
2. Water for space heating systems is not in direct contact with humans. The temperature demand to reach comfortable room temperature is lower for heating than for washing. 35° C for heating is in most cases sufficient in northern European houses and therefore used as second classification.
3. The highest category was meant for industrial processes. There were two temperatures set for the highest category in this study but they were pooled in one category. The reason is that both temperatures occurred at different urban functions and did not influence each other. A classification for every process would have increased complexity so that one category for both temperature was chosen. The temperatures occurred in processes of heat power plants and meat processing manufacturers. Planners using this method can extend the classification according to their case. This might be especially interesting if heat cascading between industrial functions is the aim. Hot water from a steel factory can be used in a brewery before it is used to heat water in residential areas. For the purpose of this study and to guarantee greater clarity, one general and flexible high temperature category was introduced.

Quality, quantity and periodicity were central in this study. Quality was important because it can give guidance for cascading. Quantity was central for a balance between demand and source of energy. Urban functions do have different heat energy consumption and production patterns. Measuring them in a quantitative way is necessary to bring demand and source of heat energy together in the needed amount. This avoids over production or shortage and is in line with the idea of an effective and efficient energy system. Periodicity was the third central point in the study. In this study a differentiation between seasons was done. The reason is that seasons are having the biggest influence in the climate zone of northern Europe. The emergence of certain qualities and quantities of resources and demands results from changing outside temperatures during the seasons. It is possible to differentiate in more categories, for example in every day or hour of a year, different months or week and weekend. These categories are, however, not as much dependent on the environmental circumstances as seasons.

As seen in chapter 2.4, spatial planning connected to energy can be done on different scales. Improving buildings is one possibility. The reason to conduct an inventory on higher scales in this study was that connecting different functions might increase the efficiency of resource use and decrease heat energy waste. The analysis on neighborhood scale might create potentials that cannot be used on building scale. The reason why a certain quality is leaving the system boundaries of a function is either its loss due to non-point source emissions or its lack of quality. A coal power plant for example needs high temperatures. It is not possible to upgrade this heat energy easily in a thermodynamic efficient way for further use. However, this waste heat energy has still enough quality for processes in other functions. In an analysis on building scale this potential would not occur because no sink of heat energy exists. In an area oriented approach other urban functions are included that have different heat energy demands. Therefore, new sinks of heat energy can occur and potentials could be used for further use in other urban functions.

The examined scale in this study was a district. The borders of the district were chosen in line with administrative borders. One reason not to analyze a whole city or country is that urban functions repeat within a city. This study argues that it is sufficient to analyze only some of them in order to clarify the idea of urban harvesting. This should keep analysis transparent and clear. The usefulness of this choice of spatial scale will be discussed in chapter 5.3.

After identifying potentials and needs, heat energy must be transported from one function to another in order to utilize it. In this study it was analyzed if existing water infrastructure can be used for this purpose. The analysis should illustrate what is needed to make a potential usable and how urban planning can influence the utilization from potentials. Other means of transport are also possible and can be considered to create for example a district heating grid.

Overview of research

This chapter was aimed to introduce the research methodology of this study. It introduced the first part of this study, the development of the HSCA, and furthermore the methods used to illustrate the HSCA for the case of St. Johann, Basel.

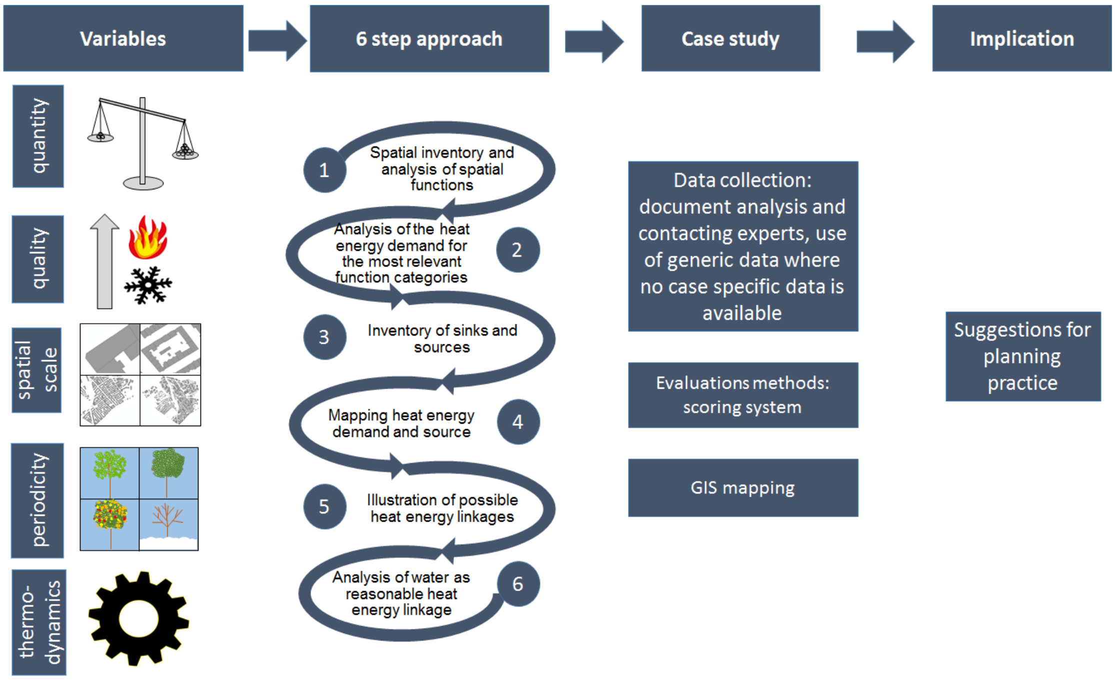

FIGURE 3.2: Overview of research in this study

In the following chapter the results of the case study are presented.

Chapter 4

Case Study Basel

This chapter is aimed to apply the HSCA for the case of St. Johann in Basel, Switzerland. The sequence of the findings follows the HSCA of chapter 3.2. The methods to collect the findings were explained in chapter 3.4.

4.1 Step 1: Spatial layout

A spatial inventory of the district St. Johann was done first. Therefore, built-up, non-built-up and water bodies were distinguished. Furthermore, industry, residential, green space, the river Rhine and the flow direction of the sewer system were classified and mapped. The sewage system is flowing in west-east direction. Residential houses were classified as one category. The reason is that the Google street view analysis revealed that they are all 3-5 story high rise buildings with similar characteristics like building age and height.

Further urban functions were power plants, office buildings, meat industry including the headquarter of the Bell AG and its meat factory, two nurseries and two hospitals including administrative buildings and workshops (see table 4.1).

TABLE 4.1: Categories of urban functions in St. Johann, Basel

Urban function	Additional information
Power plants	Incineration plant, wood fueled plant and heat power plant Volta
Residential houses	3-5 story high rise apartment buildings
Office buildings	Mixed use of production and offices
Meat processor industry	Among other companies the Bell AG
Nurseries	Learning nursery of Lehrbetriebe Basel Rehabilitation workplace of Bürgerspital Basel
Public hospital	Bürgerspital Basel, about 100 beds, administrative buildings and workshops for rehabilitation
Psychiatric clinic	Universitäre Psychiatrische Kliniken Basel, around 600 beds

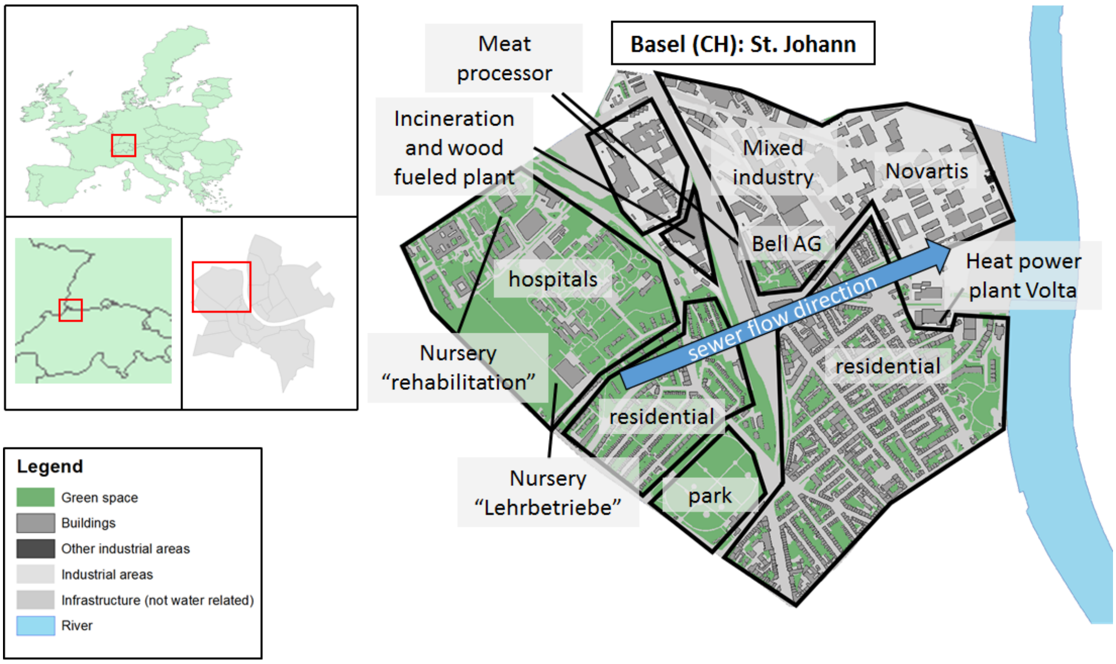

FIGURE 4.1: Map of St. Johann with urban functions, Basel. Sources: data from Vermessungsamt (2016) and Burke (2012)

4.2 Step 2: Heat energy demand

In the second step the heat energy demand for urban functions was assumed. Data per m^2 were multiplied with the building area of urban functions in order to calculate the heating load.

4.2.1 Heat energy demand per urban function

Three categories of temperature demand for heating were distinguished: low 35° C for space heating, medium 60° C hot tap water for washing and hygienic purposes and high for industrial processes.

In the first part of collecting heat energy demand data, values per m^2 for different urban functions were assumed.

Power plants

The power plants produce electricity and heat energy for different urban functions in Basel, including their own facilities (IWB, 2016b; Basel-Stadt, 2015). Because power plants consume high energy matters like coal, gas, trash or wood which cannot be won easily from waste heat energy, this study did not calculate or assume consumption values.

Residential, office areas and meat processor

About 66 % of the residential houses in St. Johan in Basel were built before 1945. Since the 1970s older houses were demolished and replaced by new concrete houses (Schürch et al., 2007). The analysis of space heating demand for residential houses were taken from Blesl et al. (2009) (see table 4.2).

Different building categories and building years result in various heat energy demands. In this study an average of 150 kWh/m^2a for heating in residential and a reduced number of 90 $kWh/(m^2a)$ for office buildings and meat processors were assumed. 150 $kWh/(m^2a)$ was chosen because the buildings in the case are big apartment buildings and building age varies between before 1945 and the 1970. The reason that the heat energy consumption for office buildings was reduced is the assumption that the production of additional heat energy through machines and computers lowers the heat energy demand in these buildings.

TABLE 4.2: Heating demand of residential areas (Blesl et al., 2009)

Building age		until 1919	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1995	1996-2000	2001-2006
Single houses	$kWh/(m^2a)$	167	150	176	150	165	165	156	101	72
Terrace house	$kWh/(m^2a)$	152	141	175	162	192	171	129	89	70
Small apartment building [a]	$kWh/(m^2a)$	180	167	117	191	169	125	101	94	65
Big apartment building [b]	$kWh/(m^2a)$	187	185	169	148	145	116	82	73	51
High rise building	$kWh/(m^2a)$				103	117				

[a]about six apartments
[b]about twelve apartments

The heating demand for drinking water was assumed accordingly to ÖNORM B8135 and guidelines. It was assumed in this study that residential buildings consume 12,5 $kWh/(m^2a)$, offices 6,25 $kWh/(m^2a)$ and meat processors $15,2kWh/animal$[1]. The Bell AG is the biggest meat processor in Switzerland. Its headquarter and several processing sites are located in St. Johann. It is assumed that half of the total meat processed by the Bell AG in Switzerland is fabricated in St. Johann[2]. It was furthermore assumed that an average animal weighs 300 kg. These assumptions resulted in the following values: 300000 pigs (300 kg), 50 0000 cows (900 kg) $\approx$ 150 000 animals, 25 000 calves (160 kg) $\approx$ 11 000 animals, 15 000 lambs (30 kg)$\approx$1 500, 8 000 000 poultry (1 kg) $\approx$ 27 000 animals.

Nurseries

Two nurseries are located in St. Johann, Basel. One nursery is located at the public hospital as part of rehabilitation measures. Another nursery for educational purposes is located southwest of the psychiatric clinic. For both nurseries a heat energy demand of 800 $kWh/(m^2a)$ was assumed (BDEW, 2009). 6,25 $kWh/(m^2a)$ was assumed as heating demand for drinking water (Normungsinstitut, 1980).

Hospitals

Two hospitals are located in St. Johann, Basel. The public hospital is located in the north-west of St. Johann and consists of administrative buildings, workshops for rehabilitation and buildings for medical purposes. Because of the mixed use a heat energy

[1]0,2 m^3 water per animal (Schwarz and Heiss, 1932), T_{low}=298 K, T_{use}=353 K, per animal: $Q = 0,2\ m^3 * 1000\ (kg/m^3) * 4,2\ kJ/(kg * K) * 65\ K = 15,2\ kWh$

[2]2009 for the Bell group in whole Switzerland: 666 417 pings, 112 788 cows, 52 583 calves, 34 484 lambs, 17 231 379 poultries

demand of 150 $kWh/(m^2a)$ was assumed. The same heat energy demand was also assumed for the psychiatric clinic.

For the psychiatric clinic a freshwater heating demand of 25 $kWh/(m^2a)$ and for the public hospital a freshwater demand of 12,5 $kWh/(m^2a)$ as a result of a mixture between administrative, medical buildings and workshops was estimated.

TABLE 4.3: Heat energy demand of selected urban functions

Urban function	Temperature classification	Heat energy demand $Q_{demand,function,T}$	Note
Power plants	high medium low	- - -	One incineration, wood fueled and gas power plant
Residential houses	high medium 60° C low 35° C	- 12,5 $kWh/(m^2a)$ 150 $kWh/(m^2a)$	South of St. Johann, 3-5 story high rise buildings
Office buildings	high medium 60° C low 35° C	- 6,25 $kWh/(m^2a)$ 90 $kWh/(m^2a)$	North of St. Johann
Meat processor	high medium 60° C low 35° C	- 15,2 $kWh/animal$ 90 $kWh/(m^2a)$	North of St. Johann
Nurseries	high medium 60° C low 35° C	- 6,25 $kWh/(m^2a)$ 800 $kWh/(m^2a)$	North-west and west of St. Johann
Public hospital	high medium 60° C low 35° C	- 12,5 $kWh/(m^2a)$ 150 $kWh/(m^2a)$	North-west of St. Johann
Psychiatric clinic	high medium 60° C low 35° C	- 25 $kWh/(m^2a)$ 150 $kWh/(m^2a)$	North-west of St. Johann

4.2.2 Demand per category

In the second part the heat energy demand analysis, values on the category scale were calculated for St. Johann, Basel. For this part the heat energy demand data for urban functions from chapter 4.1 were multiplied with the corresponding total building area of a certain category. The corresponding areas were taken from information brochures, if available, or were calculated with GIS data. Surface areas were multiplied with the numbers of floors in order to calculate the building area (see equation 4.1).

$$Q_{demand,category,T} = Q_{demand,function,T} * surface\ area * numbers\ of\ floors \qquad (4.1)$$

Residential, office areas and meat processor

St. Johann has 18 958 inhabitants with an average of $36,3\ m^2$ living space per person (Statistisches Amt, 2015). These surface numbers were taken in order to calculate $\dot{Q}_{demand,residential,T}$.

$$S_{residential} = 36,3\ m^2 * 18958 = 688211,7\ m^2 \qquad (4.2)$$

The office building area in St. Johann, Basel, is accordingly to the GIS analysis, $237684\ m^2$. It was assumed that on average office and industrial buildings are 6 stories high. The assumption includes high rise buildings and flat production sites.

Nurseries

The nursery "rehabilitation" at the public hospital consists of several greenhouses with a total area of $4084\ m^2$. The other nursery "Lehrbetriebe" has a total area of $4965\ m^2$. Both nurseries have one floor.

Hospitals

The public hospital has a total area of $20568\ m^2$ and the psychiatric clinic $19434\ m^2$. The public hospital consists mainly of lower developments while the building heights at the psychiatric clinic are higher. The average height at the public hospital was therefore assumed to be 2-story and at the psychiatric clinic 3-story.

TABLE 4.4: Heat energy demand of selected urban categories

Urban category	Temperature classification	Heat energy demand $Q_{demand,catergory,T}$	Note
Power plants	high medium low	- - -	One incineration, wood fueled and gas power plant
Residential houses	high medium 60° C low 35° C	- 8,6 GWh 103,23 GWh	South of St. Johann, 3-5 story high rise buildings
Office buildings	high medium 60° C low 35° C	- 8,91 GWh 128,35 GWh	North of St. Johann
Meat processor	high medium 60° C low 35° C	- 7,44 GWh included into office buildings (27374,56 m2)	North of St. Johann
Nursery "rehabilitation"	high medium 60° C low 35° C	- 25,53 MWh 3,27 GWh	North-west of St. Johann
Nursery "Lehrbetriebe"	high medium 60° C low 35° C	- 31,03 MWh 3,97 GWh	West of St. Johann
Public hospital	high medium 60° C low 35° C	- 514,2 MWh 6,17 GWh	North-west of St. Johann
Psychiatric clinic	high medium 60° C low 35° C	- 1,46 GWh 8, 75 GWh	North-west of St. Johann

4.2.3 Heating load per category

Heat energy demand values are giving references on how much energy is consumed per year. In order to calculate the heating load, which is the power that is needed in order heat energy a building to room temperature, the equation 3.1 (Guideline Series VDI 2067 page 2) was used.

$$\dot{Q}_{heating\ load} = Q_{demand,catergory,T}/(f_v * b_{VH}) \tag{3.1}$$

The value for $f_v = 1,054$ was taken for the location of *Freiburg im Breisgau* because no value was given for Basel and Freiburg is the closest city mentioned in the VDI guideline. It was assumed that both Basel and Freiburg are comparable because both cities are located in the Rhine valley on about the same elevation above sea-level.

The values of the full utilization per annum b_{VH} were taken from the guideline and are shown in 4.5. It was assumed that the nurseries have the same hours of full utilization per annum as the hospitals because nurseries need to be heated all time in winter.

TABLE 4.5: Heat load calculation, values for b_{VH}

Urban function	b_{VH} (hr/a)
Single house	2100
Apartment house	2000
Office building	1700
Hospital	2400
School (single shift)	1100
School (multi shift)	1300

It was furthermore assumed that the hot water heating load remains constant throughout the year while the heating load for space heating is half in spring and autumn and zero in summer.

Table 4.6: Heating load of selected urban categories and temperatures

Urban function	Temperature classification	Winter	Spring	Summer	Autumn
Power plants	high	-	-	-	-
	medium	-	-	-	-
	low	-	-	-	-
Residential houses	high	-	-	-	-
	medium 60° C	4,08 MW	4,08 MW	4,08 MW	4,08 MW
	low 35° C	48,97 MW	24,49 MW	0 MW	24,49 MW
Office buildings	high	-	-	-	-
	medium 60° C	4,97 MW	4,97 MW	4,97 MW	4,97 MW
	low 35° C	71,63 MW	35,82 MW	0 MW	35,82 MW
Meat processor	high	-	-	-	-
	medium 60° C	4,15 MW	4,15 MW	4,15 MW	4,15 MW
	low 35° C	included into office buildings			
Nursery "rehabilitation"	high	-	-	-	-
	medium 60° C	10,09 KW	10,09 KW	10,09 KW	10,09 KW
	low 35° C	1,29 MW	0,65 MW	0	0,65 MW
Nursery "Lehrbetriebe"	high	-	-	-	-
	medium 60° C	12,27 KW	12,27 KW	12,27 KW	12,27 KW
	low 35° C	1,57 MW	0,79 MW	0 MW	0,79 MW
Public hospital	high	-	-	-	-
	medium 60° C	237,97 KW	237,97 KW	237,97 KW	237,97 KW
	low 35° C	2,86 MW	1,43 MW	0 MW	1,43 MW
Psychiatric clinic	high	-	-	-	-
	medium 60° C	576,18 KW	576,18 KW	576,18 KW	576,18 KW
	low 35° C	3,46 MW	1,73 MW	0 MW	1,73 MW

In this study the heating load values of middle and low temperature processes were combined in order to estimate one heat energy demand value for each function category.

Table 4.7: Heating load of selected urban categories

Urban function	Winter	Spring	Summer	Autumn
Power plants	-	-	-	-
Residential houses	53,05 MW	28,567 MW	4,08 MW	28,57 MW
Office buildings	76,61 MW	40,79 MW	4,97 MW	40,79 MW
Meat processor	4,15 MW	4,15 MW	4,15 MW	4,15 MW
Nursery "rehabilitation"	1,30 MW	0,66 MW	10,09 KW	0,66 MW
Nursery "Lehrbetriebe"	1,58 MW	0,80 MW	12,27 KW	0,80 MW
Public hospital	3,09 MW	1,67 MW	0,24 MW	1,67 MW
Psychiatric clinic	4,03 MW	2,30 MW	0,58 MW	2,30 MW

4.3 Step 3: Inventory of possible sinks and sources

An analysis of water bodies that might function as possible sinks or sources of heat energy resulted in three categories: power plant, sewage system and river.

The bodies were calculated with equation 4.3.

$$\dot{Q}_{wastewater} = \dot{V} * \rho * c_p * \Delta T \tag{4.3}$$

Power plant

The district has three power plants: the incineration plant including a wood burning plant and the heat power plant Volta. Trash is burned at 800–1150° C throughout the year while the connected wood fueled power plant and the heat power plant Volta are demand controlled and not working from June to August (AG, 2015). The heat energy is used to feed the district heating system with about 190° C. The incineration plant, the heat power plant Volta and the wood fueled power plant have a heat energy production of about 700 GWh. The heating load was reviewed from IWB (2016a), IWB (2016b) and AG (2015) or calculated by taking the operating hours into account. In winter there are about 200 MW available while the heating load gets reduced in seasons with less demand.

Sewage system

Other sources or sinks are the waste water system that is flowing in west-east direction towards the river Rhine. Wastewater has a temperature of 10-12° C in winter and 17-20° C in summer (Knies, 2015). The sewage system in Basel is, except for few exception, a mixed system which means that sewage water and rain water are mixed in one sewer.

Water flow rates were provided by the Construction and Transport Department of the Kanton Basel-Stadt. The values are shown in table 4.8 and figure 4.2.

The heat and cool potential for the district was calculated accordingly to the equation 3.2 with the dry weather flow rates and 3 K temperature difference.

TABLE 4.8: Water flow rate for selected points in St. Johann, Basel

Location	Dry weather flow (l/s)	Strong rain water flow (l/s)
Dreirosenbrücke	450	16600
Train station	460	12510
Novartis Campus at the river Rhine next to the French border [a]	50	22000
Intersection Burgfelderstrasse/ Luzernerring	410	10060
Intersection Kannenfelstrasse/ St. Johannes-Ring	190	11450
Intersection Gustav-Wenkstrasse/ Flughafen-strasse	30	3540
Elsässerstrasse at Hühningerstrasse	20	550

[a] subsurface river, no sewage water

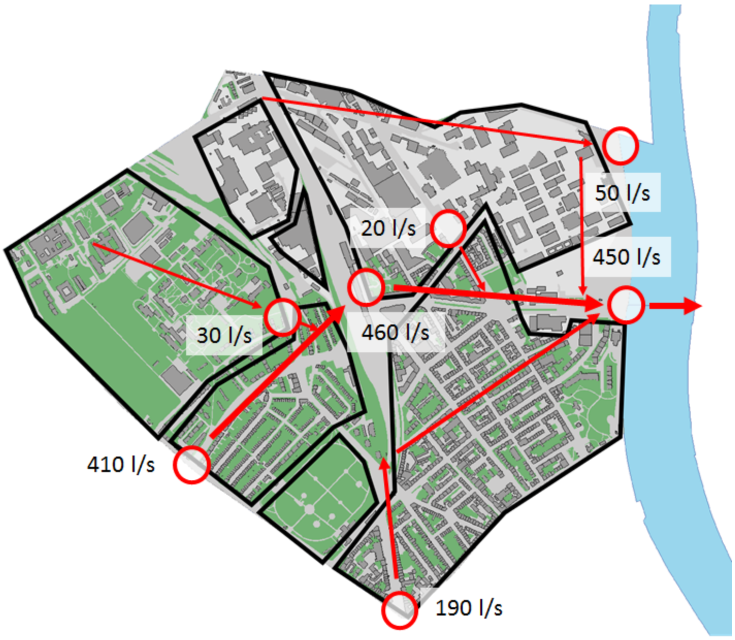

FIGURE 4.2: Location for selected wastewater measuring points in St. Johann, Basel

The flow rate for the Dreirosenbrücke, at which the wastewater is passing the river Rhine and leaving St. Johann, was taken in order to calculate the heat and cool potential for St. Johann.

River Rhine

The river Rhine is passing the district St. Johann with an annual mean temperature of 12,8° C. Temperatures in winter ranged in the years 1995-2014 between 2,2-4,4° C on cold winter days and 23,5-25,2° C in summer (BAFU, 2016a). The flow rate is from May to August the highest. 2444 m^3/s were measured in 2014 as highest and 582 m^3/s as lowest at the measuring station about 20 kilometer upstream of Basel (BAFU, 2016b).

For flow rates of 600 m^3/s and 3° C temperature difference a theoretical potential of 7,56 GW was calculated. The Swiss law forbids to heat river water above 25° C (Anton, 2016). In winter the physical properties of water set boundaries to 0° C. To avoid reaching the limits the potential was reduced by 50 % in winter and summer.

TABLE 4.9: Heat energy sources and sinks in urban water bodies

Urban function	Temperature classification	Winter	Spring	Summer	Autumn
Incineration plant and wood fueled plant	high	176 MW 190° C	135 MW 190° C	94 MW 190° C	135 MW 190° C
	medium	-	-	-	-
	low	-	-	-	-
Heat power plant Volta	high	31 MW 190° C	15 MW 190° C	-	15 MW 190° C
	medium	-	-	-	-
	low	-	-	-	-
River Rhine	high	-	-	-	-
	medium	-	-	-	-
	low	3,78 GW 2,2-4,4° C	7,56 GW, 13° C	3,78 GW, 23,5-2,2° C	7,56 GW 13° C
Sewage system	high	-	-	-	-
	medium	-	-	-	-
	low	5,67 MW, 10-12° C	5,67 MW, 12-15° C	5,67 MW, 17-20° C	5,67 MW, 13-16° C

4.4 Step 4: Map of heat energy demand and source

A 7-point scale was used for the purpose of mapping heat energy source and demand. The scale was designed to give a transparent overview of the analyzed qualitative and quantitative heat energy demand and source. High temperatures and quantities were ranked higher than lower temperature and quantities. The colored boundaries of an area are symbolizing the expected wastewater temperature. Higher temperatures of wastewater are expected in areas where comparable to other areas more hot water for hygienic purposes is used. These areas were symbolized by red boundaries while blue lines were used for colder wastewater. The dots were used to symbolize spots where waste heat energy might occur due to cooling processes.

TABLE 4.10: 7-point scale for evaluating heat energy demand and source

Rating	Quality	Quantity
+++	Temperature source T > 3° C	$\dot{Q} > 5$ GW
++	Temperature source T > 3° C	$\dot{Q} > 1$ GW
	Temperature source T > 100° C	$\dot{Q} > 100$ MW
+	Temperature source T > 20° C	$\dot{Q} > 1$ MW
0	Potential low	
-	Temperature demand T> 35-60° C	$\dot{Q} > 1$ MW
	Heat energy storage	$\dot{Q} > 1$ MW
- -	Temperature demand T> 35-60° C	$\dot{Q} > 50$ MW
- - -	Heat energy storage	$\dot{Q} > 1$ GW

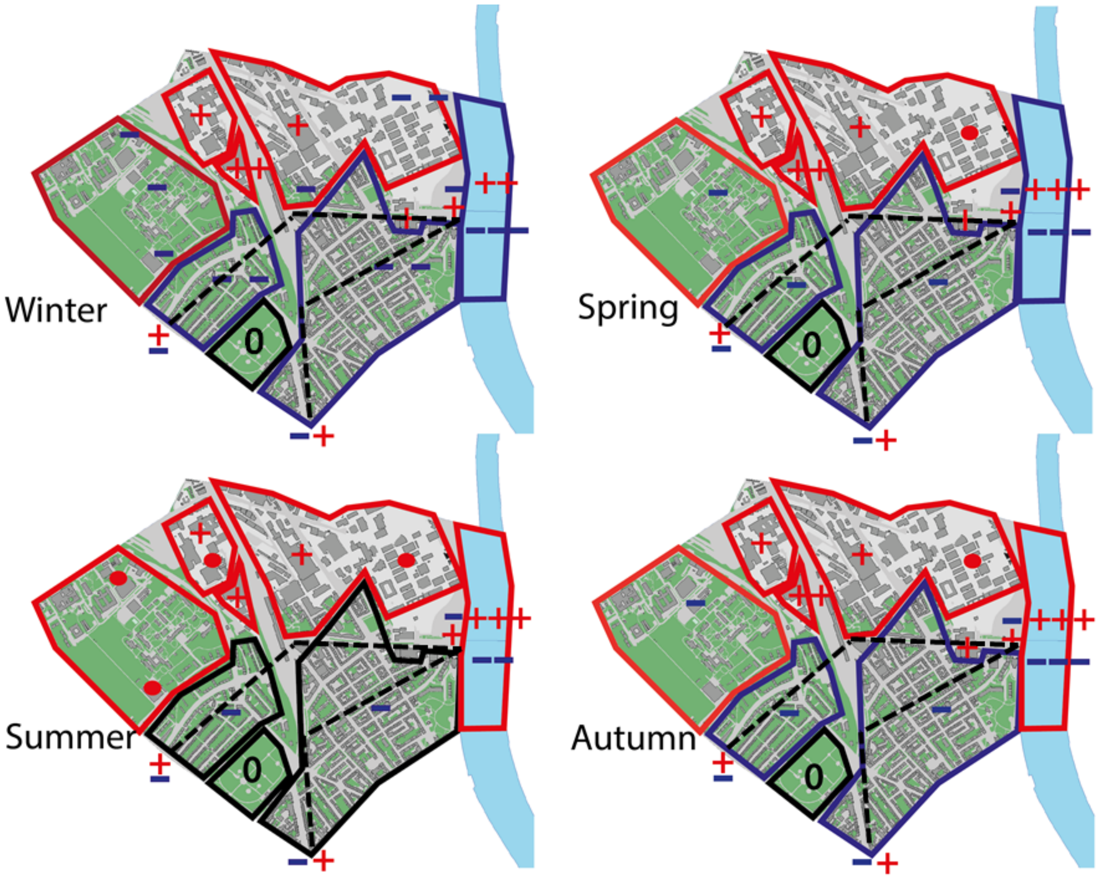

FIGURE 4.3: Seasonal heat energy potential map of St. Johann with heat energy demand and source

4.5 Step 5: Possible heat energy linkages

The mapping of heat energy demand and source showed a heat energy potential especially in north at the power plants throughout the year. Heat energy is especially needed in the south for the residential areas in winter, spring and autumn while in industrial areas the heat energy demand and source changes within a year. The river Rhine might be a source and sink of heat energy throughout the year. High temperatures are available at the power plants. Wastewater could be used for heating in residential areas. Additional heat energy from cooling processes might be available for heating.

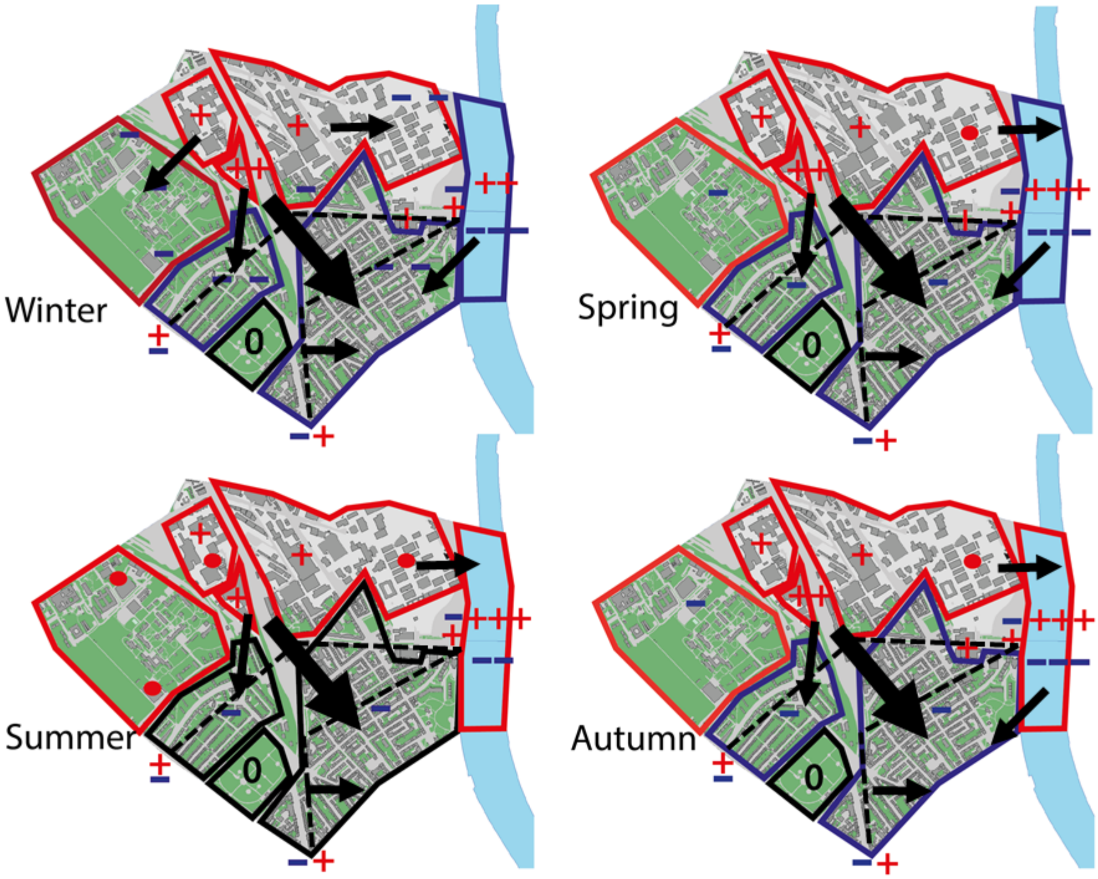

FIGURE 4.4: Seasonal heat energy potential map of St. Johann with possible energetic linkages; the arrows indicate possible heat energy streams

4.6 Step 6: Water as reasonable heat energy linkage

After the analysis of energetic heat energy potentials and demands possible means of transport with existing infrastructure were analyzed.

4.6.1 Wastewater system

Main pipes of the wastewater system were symbolized by dotted lines. The water is flowing in the pipes in west-east direction without connecting industry and residential areas. The temperature of the wastewater resulted that heat energy extraction and transport is possible.

4.6.2 River Rhine

The river Rhine is flowing from south to north and might be usable for both heating and cooling. Without building new transport infrastructure this potential can only be used in close proximity.

4.6.3 Freshwater system

The freshwater system has two main stations which feed the freshwater system in Basel. The pipes are under steady pressure to supply urban functions. Due to the remote position of the district next to the French border there are no pipes lying in south north direction throughout the whole district. However, the sketch of the freshwater system indicates that some connections between south and north exists. For further investigation the flow direction must be analyzed. This is not indicated in the map but can be different from the sewage system because the flow direction is based on pressure in the pipes and not on gravity like the sewage system.

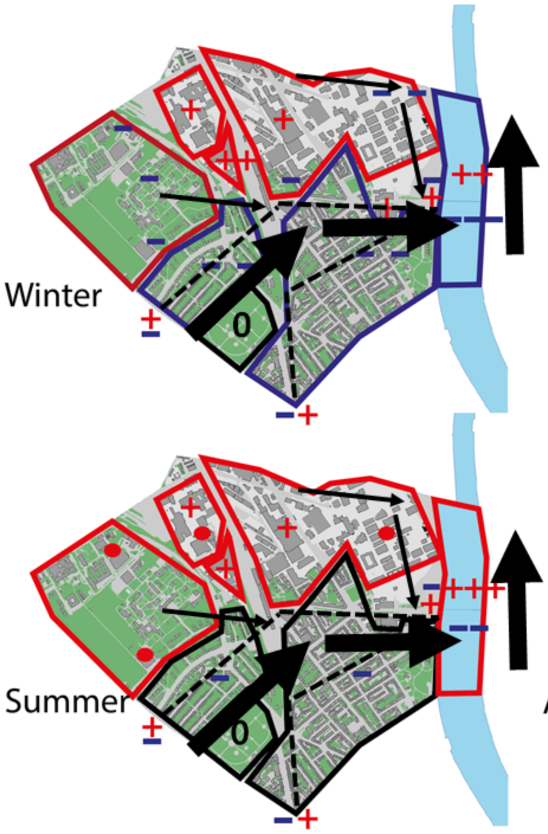

FIGURE 4.5: Seasonal heat energy potential map of St. Johann with demand and sources of heat energy, and flows of water bodies; the arrows indicate the flow direction of water

Preliminary summary

This chapter was aimed to illustrate and showcase the HSCA in St. Johann, Basel. The six steps were followed in order to create maps of possible and reasonable heat energy linkages. The heat energy demand and heat energy waste production of urban functions was illustrated. The potential of the wastewater and freshwater system and the river Rhine to function as sink, source and means of transport for heat energy were analyzed. The results of this analysis are discussed in the following chapter.

Chapter 5

Discussion

The following two chapters are aimed to discuss the findings of this study in comparison to the research questions and selected theory. It should be furthermore discussed how the HSCA contributed to answer the research questions and if the hypotheses could be verified. Furthermore, a critical reflection of the methodology is part of this chapter. Recommendations for future urban planning practice and the contribution of this study to planning theory should be given.

5.1 Reflecting theory

The theory chapter in this study included a variety of topics like sustainable urban energy development, thermodynamics and heat energy including the exergy principle, urban water use, and energy networks.

The theories used in this study were categorized into four sub chapters:

- Sustainable urban energy development
- Thermodynamics and heat energy
- Urban water use and sustainable water management
- Spatial planning, scales and networks

The selected theories in this study introduced the UHA as principle to recycle waste and use it as secondary resource. This principle was used in this study to analyze if the recycling of waste heat energy is possible. The underlying reason to use waste heat energy was the potential to reduce fossil fuel consumption. The exergy principle supports the idea to use energy for processes that fit the purpose. For space heating for example lower quality of energy (waste heat energy) might be sufficient while for a steel company high quality energy might be necessary. For an analysis of fit-for-purpose heat energy linkages, sources of heat energy, consisting of heat energy that cannot be used at this urban function any more, and demands of heat energy were coupled. In chapter 4.5 sources and demands were visualized on a map. Arrows were used in order to illustrate how heat energy could be exchanged. The study indicates that recycling of waste heat energy is possible. The findings support that heat energy at one urban function might be waste while it can be used as a resource at other functions. Heat energy from power plants or hot wastewater from hospitals can be used for space heating in residential areas. But also other sources where heat energy is not indicated as waste, e.g. from rivers, can be used for harvesting. There are evidences that the UHA can be characterized as way towards sustainable HESs. According to the Brundtland commission, development is sustainable if it "meets the needs of the present without compromising the ability of future generations" (Commission, 1987). Urban harvesting is decreasing the dependence on primary resources and therefore reduce CO_2 emissions and mitigates the depletion of resources, the social and economic vulnerability against economic and social dependence on primary resources.

Principles of physics and thermodynamics were used in this study in order to connect the urban fabric with heat energy streams. St. Johann, Basel, in Switzerland was chosen as system which should be analyzed. System boundaries were drawn accordingly with administrative boundaries. The district was not seen as isolated but as open system. This means that energy and matter exchange with the surrounding urban fabric was possible. This choice proved to be helpful because otherwise the wastewater entering St. Johann in the west could not be taken into account (see figure 4.2).

This study especially focused on water bodies as source of heat energy potentials. Especially the high heat capacity of water supports to function as source and sink of heat energy. In chapter 2.4 the water bodies were introduced as means of transport for heat energy. In this study it was analyzed if water systems like rivers or the sewage system can function as heat energy infrastructure. The showcase St. Johann, Basel, supports that water bodies can function as heat energy infrastructure. However, in contrast to electricity grids, the systems are not that flexible. Water infrastructures are characterized by a certain flow direction which is powered by gravity. An exception in the water sector might be the freshwater system in which water gets transported through pressure. The electricity grid on the other hand is not dependent on gravity. In this grid, flows can at different times flow in opposite direction. The electricity grid can be used in both directions. A consumers can draw electricity from the grid at one time and feed electricity through production with e.g. solar panels at another time. In the water system, the flow is often limited into one direction from the water plant to urban functions (freshwater) or from urban functions towards the treatment plant (wastewater). For the transportation of heat energy this means that in a water system heat energy can only be transported in one direction. The same water infrastructure cannot be used in both directions.

In this study not all parts or components of the water system were considered. One reason is that in this study the aim was to focus on developing a spatial planning approach that can be used to harvest residual heat energy with special focus on water bodies. It should furthermore introduce water as means of heat energy transport in order to create a sustainable HES. The aim was not to create an integrated urban water management plan. The showcase in St. Johann, Basel, supports that in order to create a sustainable HES, not all water bodies must be considered. Potentials were for example found in the river Rhine and the sewage system (see chapter 4.3). More water bodies like the freshwater system or ground aquifer might further contribute to establish a sustainable HESs. Bach et al. (2014) furthermore suggests to work at a range of scales and establish links with other cycles. As discussed in chapter 2.3, this can be for example done in connection to nutrients or carbon in wastewater. Further research of these potentials is necessary.

The work of Stremke et al. (2011), Bach et al. (2014) in particular and the theoretical chapter 2.4 introduced distances, spatial scale and infrastructure as essential between source and sink of heat energy. The showcase in this study illustrated that distances between sources and sinks might be considered in a different way than only metric values. Residential areas for example in the east of St. Johann are much closer to the river Rhine than in the west. Although both areas are characterized by heat energy demand for space heating, the distance and existing infrastructure might make the potential of the river more likely usable for areas closer to the river. On the other hand does the sewage system flow from west to east. The use of its potential might be possible to use at any location next to the system (see figure 4.5). This means that the wastewater system and its flow direction connects areas while no existing infrastructure creates distances. A potential created in the west for example could be used along the sewage system while potential in the north on the other hand cannot be used easily in the south. The reason is that the sewage system is not flowing in this direction. The same accounts for the river Rhine, which is flowing from south to north.

5.2 Discussion of the HSCA

The HSCA approach consists of six steps. Spatial analysis is used to find heat energy linkages and possibilities to use water as means of heat energy transport. For this analysis urban functions are distinguished, the heat energy demand is estimated and possible sources of heat energy are examined. Demand and sources are in another step visualized on a map and linkages between them were drawn. In a final step it is analyzed if water bodies could function as means of transport for heat energy.

In the following the application of the approach for the case of St. Johann is discussed.

Spatial inventory and analysis of spatial functions
Distinguishing the urban functions into categories of the same kind helped in the showcasing of the district St. Johann, Basel, to divide between areas that consume heat energy (built-up), do not influence the urban HES (non-built-up) or can store heat energy (water). The categorization made it easier to distinguish between different demands and sources while limiting the amount of work that is needed otherwise to analyze a 225,4 hectare area like St. Johann. It was possible in this study to identify areas of the same kind of buildings like residential 3-5 story apartment houses, nurseries or meat processors. Without categorization every single function would have to be analyzed separately. The result were areas of the same kind of urban functions (see figure 4.1).

Analysis of the heat energy demand for the most relevant function categories
It turned out to be difficult to estimate the heat energy demand of the urban functions in St. Johann. No specific data was available to calculate the heat energy demand for most of the urban functions. However, empirical data from other studies and guidelines could be used (see table 4.2). The analysis on a scale bigger than single buildings proved helpful in this case because errors for single buildings might have been significant while

estimations on a larger scale with many buildings can, taking the Gaussian distributions into account, reduce the error. However, more accurate data from energy companies for example would help to create a more realistic heat energy demand overview.

Inventory of sinks and sources

The case of St. Johann supports that the categorization of urban function can help to identify heat energy sources. These were mainly found in the north and water bodies: power plants, sewage system and the river Rhine (see table 4.9). The analysis of water bodies supports that they have high heat energy potentials. Especially the river Rhine proved that with a potential of 7,56 GW in spring and autumn and 3,78 GW in winter and summer has the potential in theory to heat the district of St. Johann throughout the year.

There are references that the provided data for the wastewater system cannot be fully correct. Wastewater with flowing rates of 410 and 190 l/s is entering the district of St. Johann while only 450 l/s is leaving. There is no wastewater treatment plant in this district. The plant is located on the other side of the river Rhine. All wastewater crosses the river at the Dreirosenbrücke.

Mapping heat energy demand and source

The visualization of energy potentials and demands helped in order to get a spatial overview (see figure 4.3). The overview assisted in visualizing energy sources in the case of St. Johann. Waste heat energy sources were especially available in industrial areas while residential areas in the south had higher demand for space heating.

Illustration of possible heat energy linkages

The visualization of theoretical energetic linkages helped to identify possible direction of energetic streams in the urban fabric (see figure 4.4). These could help to illustrate possible heat energy exchanges between urban functions. This is in line with the exergy principle. An energy exchange might be useful in order to reduce waste and recycle heat energy. The differentiation helped to identify heat energy demands during the year. This analyzed gave reference that heat energy is not needed in the same amount and at the same location all year. There are indications that some urban functions like nurseries or office buildings have high heat energy demands in winter while in summer they have an excess of heat energy. This can result into cooling demands in summer (see figure 4.3).

Analysis of water as reasonable heat energy linkage

The analysis of the flow direction of water resulted in a visualization of water streams on a map through arrows. The streams could be compared with the possible energy linkages of the previous step 5. In the case of St. Johann it was identified if water streams can be used to transport heat energy in the direction of the possible energy linkages. The result was that this is only partially possible. Wastewater from the north could not be used to heat residential areas in the south because the flow direction of the system was eastwards while possible heat energy streams would flow southwards. However, wastewater from the south and west of St. Johann could be used in order to heat residential houses. This means that in this case water can be used to transform possible heat energy linkages into reasonable heat energy linkages.

5.3 Reflecting approach

The approach in this study took spatial analysis as starting point. Urban functions were categorized and visualized on maps. As discussed in 5.2 this helped to simplify the analysis and increased transparency. The reason is that without categorization a visualization would have been difficult for every single urban function.

For the purpose of this study, a categorization of heat energy demand into three temperature were undertaken. The analysis of water use gave references that for residential and office areas mainly two temperatures are needed: 35° C for space heating and 60° C for hot tap water. The case analysis in this study showed that most heat energy demand is the result of space heating. For all residential areas in St. Johann for example 103,23 GWh for space heating is needed while the hot tap water demand is only 8,6 GWh (see table 4.4). This means that for the total heat energy consumption in residential areas only 7,7 % is used for heating tap water. For functions with high demand for 60° C water per m^2 like the psychiatric clinic, 14,3 % of the heat energy is used for heating water to 60° C. From an exergy perspective this means that most heat energy demands in urban functions could be fulfilled with low temperature heat energy waste.

This study took periodicity into account. It especially focused on seasons and how these influence the heat energy demand. The analysis in this study was based on the assumption that no heat energy is needed for space heating in summer and that it is half in spring and autumn. No precise data were collected for this assumption. It could be useful to analyze more deeply how periodicity influences the heat energy demand for both space heating and hot tap water in order to get more differentiated and accurate data. However, the results indicate that periodicity can be important to analyze heat energy demands, sources and possible streams. The reason is that these can change within a year and therefore generic connections between urban functions that produce and need heat energy is not possible in order to ensure supply of heat energy all year. The analysis in this study supported that in summer there is the tendency to be too much heat energy while in winter heat energy waste is limited. In summer for example computers, cooling devices and river temperatures produce heat energy or have higher potentials than in winter. At the same time is the heat energy demand, for example in residential areas, lower (see figure 4.4). It would be possible to analyze heat energy storages like urban aquifers in order to store heat energy (see chapter 2.2.4). A further analysis between differences in day and night might also be useful.

More accurate data would help in order to estimate the heat energy demand. Empirical data, which was analyzed in other cases than Basel, was used in this study. Planners using the proposed approach can try to work closer together with energy companies in order to collect data for the specific case.

The scale chosen in this study was a district. The boundaries were set accordingly to administrative boundaries. An open system approach was chosen. The selection of the system boundaries was done before any other analysis. The case of St Johann, Basel, supports that this scale is big enough to analyze different urban functions (see figure 4.1). The results furthermore support that the scale is still small enough to guarantee that the data can be handled in a transparent and visual way. It was possible to categorize different functions and set boundaries. It was furthermore possible to find heat energy sources and heat energy demands. However, the analysis was limited to one case. Further investigation of other cases must be undertaken in order to prove the usability of the scale. The case of St. Johann, Basel, however, indicates that setting boundaries accordingly with administrative boundaries might not be always useful. Urban functions for example that are located more in the west of Basel and therefore outside of the analysis could not be examined. These urban function can have an influence on the wastewater temperature that is flowing into St. Johann. Although the distance between St. Johann and other parts in the west might be big, the wastewater system is connecting these areas.

It could be useful in further studies to draw more flexible boundaries. In this approach the area of interest, in which heat energy demands should be examined and energetic linkages found, could be oriented accordingly to administrative boundaries. However, the catchment area of the possible energy streams, in this case especially of the water bodies, could be more flexible. In the case of St. Johann, the analysis for example could be extended for the wastewater system to the catchment area in the West-Basel. This would for example allow to find and use potentials in St. Johann that are created outside the examined case in West-Basel.

5.4 Reflecting methods

Literature review

The review of theories gave insights into the definition of sustainable HESs and the use of water bodies in such a system. The review furthermore provided ideas and limits on how such a system can be created for heat energy. The UHA and the exergy principle gave reference to use secondary resources while information about networks gave references about scale and transport possibilities for heat energy.

The literature review provided enough information in order to develop the HSCA. Variables like quality, quantity, periodicity could be combined with thermodynamic laws including the exergy principle, and spatial scales in combination with energy networks in order to develop a spatial planning approach that could help to establish a sustainable HES.

The subchapter about urban water use and sustainable water management gave reference that using water and managing it must "consider all parts, components , of the system" (Bach et al., 2014). This could help to make measures "socially acceptable, economically feasible and not harmful to biodiversity" (Stremke et al., 2011). Further research about the influence of using urban water bodies for heat energy purposes must be undertaken.

Evaluation methods

In order to visualize energy potentials and demands, GIS data and programs like ArcMap and Illustrator were used. The showcase St. Johann, Basel, indicated that visualization of potentials can help to draw energetic linkages in an UHA for waste heat energy and water bodies. A rating systems was chosen in order to score energy potentials and rank different qualities and quantities. It was possible to rank criteria in this study. However, some aspects of the energy analysis got lost in this simplification. For example it was in this study not distinguished between different temperatures in order to rank the heating load (see table 4.10). Only one value was for transparency reasons used to estimate the heating load (see table 4.7).

It was furthermore difficult to distinguish between heat energy sources and sinks. The river Rhine for example could function as both. The same accounts for the sewage system. For specific urban functions it was also difficult to distinguish if they are a sink or a source. A hospital for example has higher demands for 60° C hot water and therefore also produces hotter wastewater. The hospital on the other hand has also space heating demand. The methodology chosen in this study focuses on the exchange between different urban functions. In the case of the hospital it might be possible to use the own hot wastewater for space heating. Such an approach was for example discussed by Meggers and Leibundgut (2011).

In order to indicate expected areas of higher wastewater temperature, red boundaries around an area were drawn. It is arguable if this approach is sufficient to show wastewater potentials or if this might mislead to the assumption that the whole area has in general the potential to function as heat energy source. The methodological difficulty was to visualize different temperature and indicate if these areas can function as source or sink of heat. As explained before, in the case of the hospital for example, both facilities have heat energy demand for space heating and could function as heat energy source because of high wastewater temperature. Further research can be undertaken in order to find a method which visualize information rich data in an aggregated and transparent way.

The case of St. Johann, Basel, also indicated that heat energy potentials are not limited to water bodies. Computers in office buildings and cooling devices from meat processors are producing heat. This heat energy is usually released into the air. An exchange of this heat energy with wastewater as mode of transport might be possible and could be investigated further. Visualizing these might be another possibility for further research.

Data collection

Three different ways of collecting data were used in this study: internet document analysis, document analysis and expert contacting to obtain data. Internet document analysis and document analysis were used in order to find specific and empirical data for the case. In some circumstances, no precise data was available. The heating demand of residential areas for example is based in this study on empirical data. Contacting experts to obtain data was used to get specific information. The map of the wastewater system and flow rates for example was provided through this way.

The HSCA requires different sort of data. Without the availability of these the analysis could not be conducted. It proved therefore helpful to use empirical data in cases where no exact data is available. This might distort the results. However, the error can be minimized if data is chosen that is likely to be comparable with the situation of the case. The residential heat energy demand data for example was chosen from empirical data that was collected in the same climate zone for buildings with the same age, height and shape (apartment buildings) because it was assumed that these variables are influencing the heat energy demand most.

The table 4.2 indicates another characteristic of buildings. Since the beginning of the 1990s the heating demand has been reduced more than in the years before. A reason could be stricter regulations concerning heat energy consumption in new buildings. This would mean for spatial planning that the changing demand for space heating is likely to be lower in future. It could be helpful in practice to consider changing heating demands in order to plan future HES.

Calculations

The chosen equations were usable in order to estimate heat energy demand and heating load of buildings and water bodies. The use of Microsoft Excel was useful in order to conduct the calculations. The results were transferred manually into tables and figures with Illustrator. For further research it could be helpful to develop an interface between Excel and ArcMap or other programs with the ModelBuilder in order to automate the transfer of data. A simple input template could make the approach easily usable for other researchers and decision makers.

Chapter 6

Conclusion

6.1 Answering the research questions

Three research questions were the basis for designing the methodology of this research. The following paragraphs are meant to discuss if and how these questions were answered.

The first research questions of this study was: What variables are important to identify and use urban heat energy potentials in order to create sustainable HESs?

The selected theories resulted that quality, quantity, spatial scales in combination with energy networks, periodicity and thermodynamic laws are central in heat energy planning. The approach in this study takes these variables into account.

Quality, quantity and periodicity are important in order to identify the amount of energy that is available or needed at a certain time. Without these variables, a sufficient supply could not be guaranteed. Spatial scales and networks give reference on the spatial distribution of energy and opens possibilities to create possible and reasonable linkages. Taking the flow direction of water for example into account in order to connect areas is an example. Thermodynamic laws help to draw boundaries around an analysis and introduce the exergy principle into spatial planning. Heat energy exchanges from low to high temperature like from rivers to power plants are not efficient from thermodynamic perspective. Instead, the heat energy source and demand should have about the same quality. This helps to identify how resources can be used in an efficient and effective way in order to reduce dependence on high quality energy carriers.

The second research question was: How can a spatial planning approach help to develop a sustainable HESs and what are the benefits of such a system?

Spatial planning can help to develop an analytic approach that can be used in decision making processes for future planning. This approach can include the variables quality, quantity, spatial scales in combination with energy networks, periodicity and thermodynamic laws and connect these with the urban fabric. It is possible to show the spatial distribution of heat energy for both, the demand and source. Furthermore, this approach allows to draw linkages between these. Decisions can be made on this basis on which linkages should be utilized and how these connections could be made. It is furthermore possible to take the analysis as decision foundation on where to build an urban function. This decision can be based on the aim to use waste heat energy. The urban function can therefore be built where either it can use existing heat energy sources or where it can function as heat energy source for other functions.

The benefits of a sustainable HES are the reduction of primary resource consumption. Such resources are for example fossil fuels. The system is sustainable in a way that it reduces both the consumption and dependence on primary resources. It therefore reduces CO_2 emissions and decreases social vulnerability in case of resource scarcity.

The third research question in this study was: What findings can be derived from the spatial planning approach and the case study in order to identify the contribution of urban water bodies towards sustainable HESs?

The theoretical analysis showed that water has a high heat capacity and that it therefore can store heat energy better than air or soil. The physical property of water furthermore supports the idea of using water as means of transport in order to connect sources and demands of heat. The existing water infrastructure in the urban fabric creates connections between different urban functions that can do both: function as source and sink of heat energy and as means of transport for the potentials.

The analysis of St. Johann, Basel, revealed that several water bodies are part of the urban fabric. These were for example the river Rhine, the wastewater and freshwater system. The analysis indicated that these systems are not used for energetic purposes yet. There were for example no temperature data available for the water in the sewage system and no case was found in document analysis or expert contacting which indicated that the Rhine is already used as sink or source of heat. Especially the river Rhine proved that with a potential of 7,56 GW in spring and autumn and 3,78 GW in winter and summer has the potential to heat the district of St. Johann.

Another specific of the case is that water infrastructure in Basel is owned by different institutions. The freshwater system for example is owned by the company iwb, the wastewater system by the city itself and the river Rhine is managed by federal offices. This separation of water management into different institutions might, as literature indicates, also be found in other places. Next to the separation in the energy sector this might impede the creation of sustainable energy systems. Further investigation is, however, necessary.

There are evidences that the water infrastructure is connecting different urban functions and that it is creating a network. Distances between urban functions and the possibility to use water infrastructure to transport energy potentials are not explicit dependent on metric numbers. The possibility to use water as means of transport are much more dependent on the flow direction of the water.

There are some limitation of water bodies as means of transport. One limitation is for example that, unlike the electricity grid for transporting electricity, there is not one water body that can be used for transporting heat. Water infrastructure consists of sewers, freshwater systems, rivers and other water bodies. Connecting urban functions in order to create effective and efficient systems might only be possible if several water bodies are used. Heat energy in the sewage system for example can only be transported in one direction because of gravity. In order to create effective and efficient system, another water body or other modes of transport must be used to transfer heat energy in the other direction.

6.2 Findings for spatial and urban planning practice and theory

The analysis of theories and the showcase in St. Johann, Basel, indicate that the UHA can be used in order to recycle heat energy waste from water bodies and use it as secondary resource. This study furthermore supports the idea to use water bodies as source and sink of heat energy and furthermore as means of transport. This study therefore contributes to the theory on urban harvesting and especially the work of Agudelo-Vera et al. (2012) and Leduc and Van Kann (2013). It adds variables that need to be identified in order to harvest heat energy from water bodies and shows reasonable transport possibilities. The distinction between different seasons and mapping these differences is another new aspect of this study that contributes to the UHA and the mentioned studies. Waste heat energy from the sewage system for example could be used in residential areas for space heating in winter. In summer the sewage system could be used for cooling purposes. Visualization of potentials at different periods on a map, drawing connections between sources and demands and showing flows of water can help to identify opportunities.

Challenges in spatial planning might be the institutional separation of water bodies and energy sector. For every water system in the analyzed case a different company is responsible. The freshwater system is for example owned by the iwb, which is also the owner of the power plants. The river and the wastewater systems is, however, owned by other institutions. The analysis in this study indicated that different urban water bodies might have to be used in order to create effective and efficient systems. The reason is that water is flowing in the systems in a certain direction. The sewage system is flowing for example towards the treatment plant and the river towards the sea. The flow direction in the freshwater system might be of interest to use because the flow is not driven by gravity but pressure in the pipes. Flow directions in the opposite direction of the sewage system might be possible.

The challenges for spatial planners in order to use water bodies might be furthermore to expand the boundaries of their analysis beyond administrative frontiers. A heat energy source might not be located next to objects that have heat energy demands. The heat energy source might be located further away outside the system boundary. However, the sewage system for example might connect the two locations. Including catchment areas of water bodies into the analysis might help to solve this issue. The physical properties of water, e.g. the flow as a result of gravity, might mean for future planning that high energy processes with high temperature heat energy waste might be located at areas that are upstream. This would allow to use the water infrastructure to transport the heat energy downstream to locations with heat energy demand.

The findings in this study are based on theory and the analysis of one case. There are evidences that the HSCA in this study can be useful in order find and link heat energy potentials. However, the benefits and limitations of the HSCA must be verified through further investigations. These could include for example more water bodies and more flexible boundaries.

Three variables have been used in this study to estimate heat energy demands and sources: quality, quantity and periodicity. The quality gave reference where energy potentials can be found (exergy principle), the quantity was used in order to identify if enough heat energy is available and periodicity was used in order to ensure that supply is guaranteed throughout the year. It was shown in this study that periodicity has an influence on heat energy demand and availability. If during the year a shortcut or overproduction occur, storage possibilities must be found in order to close cycles. Water aquifers might be a possibility. If the quality is not fitting, either a quality surplus or a lack of quality is occurring. A quality surplus should be avoided because from an exergy point of view heat energy potentials are not used in an energetic favorable way in order to create effective and efficient systems. Additional urban functions could be introduced that can close gaps. A lack of quality must be compensated through e.g. upgrading with additional energy. A lack of quantity is most difficult to offset. For spatial planning a lack of quantity means to widen the analysis and find additional heat energy resources.

The conclusion of this study is therefore the following. The UHA is useful in order to use waste as secondary resource. Water is possible to function as sink and source of heat energy and has high potential in order to create effective and efficient HESs. Of special interest is the high heat capacity of water. At the moment institutional fragmentation and the lack of reliable data for both water (e.g. temperatures in wastewater systems) and heat energy demand for urban functions might impede the application of water as heat energy resource and grid. Furthermore, the existing urban fabric with its infrastructure sets limits on the application of water bodies as means of transport. This study has therefore three suggestions: 1. Future spatial planning should analyses if institutional fragmentation is impeding the application of water infrastructure as heat energy resource and grid. 2. Data for estimating demand and source of heat energy should be collected in order to have more precise predictions. 3. Planning practice should take energy flows and especially the physical processes which are responsible for the flows into account. Plans should not oppose the (physical) possibility to exchange heat energy between functions.

If spatial planning takes these advises into account, possible energetic linkages can become reasonable through the connection with water bodies. The development of sustainable HESs can contribute to guide society into the third energy landscape.

Bibliography

AG, Holzkraftwerk Basel (2015). *Jahresbericht 2014*.

Agudelo-Vera, CM, WRWA Leduc, AR Mels and HHM Rijnaarts (2012). “Harvesting urban resources towards more resilient cities”. In: *Resources, Conservation and Recycling* 64, pp. 3–12.

Anton, S (2016). *Thermische Nutzung Rhein, Schlussbericht Potentialstudie*.

Atkins, P and J de Paula (2010). *Atkins' Physical Chemistry*. OUP Oxford. ISBN: 9780199543373.

Bach, PM, W Rauch, PS Mikkelsen, DT McCarthy and A Deletic (2014). “A critical review of integrated urban water modelling – Urban drainage and beyond”. In: *Environmental Modelling & Software* 54, pp. 88 –107. ISSN: 1364-8152.

BAFU, Bundesamt für Umwelt Abteilung Hydrologie (2016a). *Jahrestabellen Abfluss 2014, Rhein - Rheinfelden, Messstation*. Published: 2016-03-16.

– (2016b). *Jahrestabellen Temperatur 2014, Rhein - Weil, Palmrainbrücke*. Published: 2016-03-21.

Balaras, CA, K Droutsa, E Dascalaki and S Kontoyiannidis (2005). “Heating energy consumption and resulting environmental impact of European apartment buildings”. In: *Energy and buildings* 37.5, pp. 429–442.

Bansal, R (2006). *Fundamentals of engineering electromagnetics*. CRC press.

Basel-Stadt, Kanton (2015). *Statistisches Jahrbuch des Kantons Basel-Stadt 2015*.

Basel-Stadt, Tiefbauamt (2016). *Gewässer, Abwasser und Kosten*. http://www.tiefbauamt.bs.ch/abwasser.html. Accessed: 2016-05-20.

Baynes, TM (2009). “Complexity in urban development and management”. In: *Journal of Industrial Ecology* 13.2, pp. 214–227.

BDEW, Bundesverband der Energie-und Wasserwirtschaft e.V. (2009). *Erdgas in Gärtnereien*.

Becker, S, A Bryman and H Ferguson (2012). *Understanding research for social policy and social work: themes, methods and approaches*. Policy Press.

Blatter, J (2001). "Integrative Symbole und regulative Normen bei der Institutionenbildung. Erkenntnisse vom Gewässerschutz am Bodensee". In: *Zeitschrift für Internationale Beziehungen*, pp. 5–40.

Blesl, M, S Kempe, M Ohl, U Fahl, A König, T Jenssen and L Eltrop (2009). "Wärmeatlas Baden-Württemberg-Erstellung eines Leitfadens und Umsetzung für Modellregionen". In: *Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart*.

Blokker, EJM, AM van Osch, R Hogeveen and C Mudde (2013). "Thermal energy from drinking water and cost benefit analysis for an entire city". In: *Journal of Water and Climate Change* 4.1, pp. 11–16.

Broto, VC, A Allen and E Rapoport (2012). "Interdisciplinary perspectives on urban metabolism". In: *Journal of Industrial Ecology* 16.6, pp. 851–861.

Brown, RR (2008). "Local institutional development and organizational change for advancing sustainable urban water futures". In: *Environmental management* 41.2, pp. 221–233.

Burke, R (2012). *Europe*. http : / / www . arcgis . com / home / item . html ? id = 6d611f8d87d54227b494d4c3becef6a0/. Accessed: 2016-06-14.

Cao, ZK, H Han, B Gu, L Zhang and ST Hu (2009). "Application of seawater source heat pump". In: *Journal of the Energy Institute* 82.2, pp. 76–81.

Commission, Brundtland (1987). "Our common future, Chapter 2: Towards sustainable development". In: *World Commission on Environment and Development (WCED). Geneva: United Nation.*

Crabtree, GW and NS Lewis (2007). "Solar energy conversion". In: *Physics today* 60.3, pp. 37–42.

de Boer, J and C Zuidema (2015). "Towards an integrated energy landscape". In: *Proceedings of the Institution of Civil Engineers-Urban Design and Planning* 168.5, pp. 231–240.

Deilmann, C (2009). "Urban metabolism and the surface of the city". In: *Guiding Principles for Spatial Development in Germany*. Springer, pp. 1–16.

Dincer, I (2000). "Thermodynamics, exergy and environmental impact". In: *Energy sources* 22.8, pp. 723–732.

Droege, P (2002). “Renewable energy and the city: Urban life in an age of fossil fuel depletion and climate change”. In: *Bulletin of Science, Technology & Society* 22.2, pp. 87–99.

Elías-Maxil, JA, JP van der Hoek, J Hofman and L Rietveld (2014). “Energy in the urban water cycle: Actions to reduce the total expenditure of fossil fuels with emphasis on heat reclamation from urban water”. In: *Renewable and Sustainable Energy Reviews* 30, pp. 808–820.

EnergieAgentur.NRW (2010). *Leitfaden Energieeffizienz für Krankenhäuser.*

Erbe, V and M Schütze (2005). “An integrated modelling concept for immission-based management of sewer system, wastewater treatment plant and river”. In: *Water Science & Technology* 52.5, pp. 95–103.

eurostat (2016). *Energy balance sheets — 2014 data — 2016 edition.*

Farhangi, H (2010). “The path of the smart grid”. In: *IEEE power and energy magazine* 8.1, pp. 18–28.

Flyvbjerg, B (2006). “Five misunderstandings about case-study research”. In: *Qualitative inquiry* 12.2, pp. 219–245.

Frijns, J, J Hofman and M Nederlof (2013). “The potential of (waste) water as energy carrier”. In: *Energy Conversion and Management* 65, pp. 357–363.

Gandy, M (2004). “Rethinking urban metabolism: water, space and the modern city”. In: *City* 8.3, pp. 363–379.

Goodier, CI, K Chmutina, E Poulter and P Stoelinga (2013). “Potential for seawater district heating and cooling in the UK”. In: *Proceedings of the ICE - Energy, 3, paper 1200016, 5pp.*

Groothuis, DG, HR Veenendaal and HL Dijkstra (1985). “Influence of temperature on the number of Legionella pneumophila in hot water systems”. In: *Journal of applied bacteriology* 59.6, pp. 529–536.

Guy, S and S Marvin (2000). “Models and pathways: the diversity of sustainable urban futures”. In: *Achieving sustainable urban form*, pp. 9–18.

Hepbasli, A (2008). “A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future”. In: *Renewable and Sustainable Energy Reviews* 12.3, pp. 593–661.

Hofman, J, R Hofman-Caris, M Nederlof, J Frijns and M Van Loosdrecht (2011). “Water and energy as inseparable twins for sustainable solutions”. In: *Water Science & Technology* 63.1, pp. 88–92.

IWB (2015). *IWB Trinkwasser - Das kostbare Lebenselixier.*

– (2016a). *Heizkraftwerk Volta.* http://www.iwb.ch/de/unternehmen/kraftwerke/basel/heizkraftwerk_volta.

– (2016b). *Umweltbericht 2015 der KVA Basel.*

Kanchev, H, D Lu, F Colas, V Lazarov and B Francois (2011). "Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications". In: *IEEE transactions on industrial electronics* 58.10, pp. 4583–4592.

Kenway, SJ, PA Lant, A Priestley and P Daniels (2011). "The connection between water and energy in cities: a review". In: *Water Science and Technology* 63.9, pp. 1983–1990.

Knies, J (2015). "Durch Raumanalysen das energetische Potenzial von Abwasser heben". In: *Wasser und Abfall* 1, p. 2.

Lambert, FL (2002). "Disorder - A Cracked Crutch for Supporting Entropy Discussions". In: *Journal of Chemical Education* 79.2, p. 187.

Leduc, WRWA and FMG Van Kann (2013). "Spatial planning based on urban energy harvesting toward productive urban regions". In: *Journal of Cleaner Production* 39, pp. 180–190.

Leduc, WRWA, CM Agudelo-Vera, R Rovers and AR Mels (2009). "Expanding the exergy concept to the urban water cycle". In: *SASBE 2009 Proceedings of the 3rd CIB International Conference on Smart and Sustainable Built Environments, Delft, The Netherlands, 15-19 June 2009.*

Lee, KS (2013). "Underground Thermal Energy Storage". In: London: Springer London. Chap. Underground Thermal Energy Storage, pp. 15–26. ISBN: 978-1-4471-4273-7.

Leonhardt, C and D Müller (2010). *Kombination von Latentwärmespeichern mit Solarthermie.* Vienna University of Technology, Department of Building Physics and Building Ecology.

Lewis-Beck, M, A Bryman and T Liao (2004). *Encyclopedia of Social Science Research Methods.* SAGE Publications.

Li, F, W Qiao, H Sun, H Wan, J Wang, Y Xia, Z Xu and P Zhang (2010). "Smart transmission grid: Vision and framework". In: *IEEE transactions on Smart Grid* 1.2, pp. 168–177.

Lund, H, AN Andersen, PA Østergaard, BV Mathiesen and D Connolly (2012). "From electricity smart grids to smart energy systems–a market operation based approach and understanding". In: *Energy* 42.1, pp. 96–102.

Manteghi, G and D Remaz (2015). "Water Bodies an Urban Microclimate: A Review". In: *Modern Applied Science* 9.6, p1.

Marlow, DR, M Moglia, S Cook and DJ Beale (2013). "Towards sustainable urban water management: A critical reassessment". In: *water research* 47.20, pp. 7150–7161.

Meggers, F and H Leibundgut (2011). "The potential of wastewater heat and exergy: Decentralized high-temperature recovery with a heat pump". In: *Energy and Buildings* 43.4, pp. 879–886.

Metzger, B (2010). *Bauherren-Handbuch: schlüsselfertig bauen vom Architektenhaus bis zum Bauträgerobjekt;[vom Baugrubeaushub bis zur Schlüsselübergabe; auf CD-ROM: Baukostenrechner, Bauzeitenplan, Abnahmeprotokolle, Kaufverträge und Gesetze; mit aktueller Energieeinsparverordnung und neuer HOAI].* Haufe-Lexware.

Mikkonen, L, J Rämö, RL Keiski and E Pongrácz (2013). "Heat recovery from wastewater: Assessing the potential in Northern areas". In: *Water research at the University of Oulu. Proceedings of the WaRes Conference*, pp. 161–164.

Miltenburg, I (2008). "Exploring the technical and economic feasibility of using the urban water system as a sustainable energy source". In: *Thermal Science* 12.4, pp. 35–50.

Mitchell, C, D Fam and D Cordell (2012). "Effectively managing the transition towards restorative futures in the sewage industry: a phosphorus case study". In: *Water sensitive cities*, pp. 83–96.

Nations, United (2014). "World Urbanization Prospects: The 2014 Revision, Highlights. Department of Economic and Social Affairs". In: *Population Division, United Nations.*

Noorman, KJ and G de Roo (2011). *Energielandschappen, de 3de generatie - over regionale kansen op het raakvlak van energie en ruimte.* In Boekvorm Uitgevers.

Normungsinstitut, Österreichisches (1980). *ÖNORM B 8135, 1980: Vereinfachte Berechnung des zeitbezogenen Wärmeverlustes (Heizlast) von Gebäuden.*

Omer, AM (2008). "Energy, environment and sustainable development". In: *Renewable and sustainable energy reviews* 12.9, pp. 2265–2300.

Opschoor, H and L Reijnders (1991). "Towards sustainable development indicators". In: *In search of indicators of sustainable development.* Springer, pp. 7–27.

Pahl-Wostl, C (2007). "The implications of complexity for integrated resources management". In: *Environmental Modelling & Software* 22.5, pp. 561–569.

Pasqualetti, M (2012). "Reading the changing energy landscape". In: *Sustainable energy landscapes: Designing, planning, and development*, pp. 11–44.

Pérez-Lombard, L, J Ortiz and C Pout (2008). "A review on buildings energy consumption information". In: *Energy and buildings* 40.3, pp. 394–398.

Persson, U and S Werner (2011). "Heat distribution and the future competitiveness of district heating". In: *Applied Energy* 88.3, pp. 568–576.

Peter, S, K Schaber, K Stephan and F Mayinger (1998). *Thermodynamik 1. Einstoffsysteme. Grundlagen und technische Anwendungen, 15. Auflage.* Springer Verlag, Berlin. ISBN: 978-3-642-30098-1.

Porges, F. (2001). "4 - Heat and thermal properties of materials". In: *{HVAC} Engineer's Handbook (Eleventh Edition).* Ed. by F. Porges. Eleventh Edition. Oxford: Butterworth-Heinemann, pp. 45 –68. ISBN: 978-0-7506-4606-2.

Rizwan, AM, LYC Dennis and LIU Chunho (2008). "A review on the generation, determination and mitigation of Urban Heat Island". In: *Journal of Environmental Sciences* 20.1, pp. 120–128.

Rode, S (2010). "Integrated approach to solid waste management in Pune city". In:

Roggema, Rob (2013). *The design Charrette: ways to envision sustainable futures.* Springer Science & Business Media.

Rosen, MA and I Dincer (2001). "Exergy as the confluence of energy, environment and sustainable development". In: *Exergy, an International journal* 1.1, pp. 3–13.

Rovers, R (2007). "Urban Harvest, and the hidden building resources". In: *CIB World Congress*, pp. 14–18.

Sanders, KT and ME Webber (2015). "Evaluating the energy and CO 2 emissions impacts of shifts in residential water heating in the United States". In: *Energy* 81, pp. 317–327.

Schürch, B, A Sartoris and M Drilling (2007). "Quartierprofil St. Johann (Basel)". In: *Nationales Forschungsprojekt: Soziales Kapital und nachhaltige Quartierentwicklung, NFP54.*

Schwarz, O and HA Heiss (1932). *Bau, Einrichtung und Betrieb öffentlicher Schlacht- und Viehhöfe: Handbuch der Schlachthofwissenschaft und Schlachthofpraxis für Schlachthofleiter, Schlachthoftierärzte, Bürgermeister, Stadtbaubehörden, Sanitäts-und Verwaltungsbeamte, Studierende der Veterinärmedizin, das Bauwesen und die Maschinentechnik; mit zahlr. Tab.* Springer.

Shukuya, M (2009). "Exergy concept and its application to the built environment". In: *Building and Environment* 44.7, pp. 1545–1550.

Sioshansi, FP (2011). "So What's So Smart about the Smart Grid?" In: *The Electricity Journal* 24.10, pp. 91–99.

Statistisches Amt, Kanton Basel-Stadt (2015). *Kurzportraits 2015 Basler Quartiere und Gemeinden.*

Stremke, S and J Koh (2010). “Ecological concepts and strategies with relevance to energy-conscious spatial planning and design”. In: *Environment and planning. B, Planning & design* 37.3, p. 518.

Stremke, S, A Van Den Dobbelsteen and J Koh (2011). “Exergy landscapes: exploration of second-law thinking towards sustainable landscape design”. In: *International Journal of Exergy* 8.2, pp. 148–174.

Swissweg (2009). *Schlachtzahlen Schweiz.* http://www.swissveg.ch/schlachtzahlenCH. Accessed: 2016-06-20.

Szulecki, K and K Westphal (2014). “The cardinal sins of European energy policy: Non-governance in an uncertain global landscape”. In: *Global Policy* 5.s1, pp. 38–51.

Vandevyvere, H and S Stremke (2012). “Urban planning for a renewable energy future: Methodological challenges and opportunities from a design perspective”. In: *Sustainability* 4.6, pp. 1309–1328.

VDI, Verein Deutscher Ingenieure (1993). *VDI-Richtlinien-VDI 2067 Blatt 2. Berechnung der Kosten von Wärmeversorgungsanlagen Raumheizung.*

Vermessungsamt, Geoportal Kanton Basel-Stadt Grundbuch und (2016). *Kantonale Geodaten Basel-Stadt.* http://www.geo.bs.ch/. Accessed: 2016-05-26.

Vliet, Bas JM van (2012). “Sustainable innovation in network-bound systems: implications for the consumption of water, waste water and electricity services”. In: *Journal of Environmental Policy & Planning* 14.3, pp. 263–278.

Wong, THF and RR Brown (2009). “The water sensitive city: principles for practice”. In: *Water Science and Technology* 60.3, p. 673.

Xu, M, JC Crittenden, Y Chen, VM Thomas, DS Noonan, R Desroches, MA Brown and SP French (2010). “Gigaton problems need gigaton solutions 1”. In: *Environmental science & technology* 44.11, pp. 4037–4041.

Yamaguchi, Y, Y Shimoda and M Mizuno (2007). “Transition to a sustainable urban energy system from a long-term perspective: case study in a Japanese business district”. In: *Energy and buildings* 39.1, pp. 1–12.

Yao, R and K Steemers (2005). “A method of formulating energy load profile for domestic buildings in the UK”. In: *Energy and Buildings* 37.6, pp. 663–671.

Zhu, X (2014). “GIS and urban mining”. In: *Resources* 3.1, pp. 235–247.

TABLE A.1: Documents used for the HSCA in St. Johann, Basel

Step	Document	Purpose	Year	Author
1	GIS data for Basel	Spatial overview of Basel	2016	Vermessungsamt (2016)
	GIS map Europe	Spatial allocation of case study in Europe	2012	Burke (2012)
2	Wärmeatlas Baden-Württemberg-Erstellung eines Leitfadens und Umsetzung für Modellregionen	Estimate space heating demand for residential and office buildings	2009	Blesl et al. (2009)
	Quartierprofil St. Johann (Basel)	Information urban fabric	2007	Schürch et al. (2007)
	ÖNORM B 8135, 1980: Vereinfachte Berechnung des zeitbezogenen Wärmeverlustes (Heizlast)von Gebäuden	Estimate hot tap water demand	1980	Normungsinstitut (1980)
	Bau, Einrichtung und Betrieb öffentlicher Schlacht-und Viehhöfe: Handbuch der Schlachthofwissenschaft und Schlachthofpraxis	Estimate heat energy demand for meat processor	1932	Schwarz and Heiss (1932)

	Erdgas in Gärtnereien	Estimate heat demand of nurseries	2009	BDEW (2009)
	Statistisches Jahrbuch des Kantons Basel-Stadt 2015	Energy production of power plants	2015	Basel-Stadt (2015)
	VDI-Richtlinien-VDI 2067 Blatt 2. Berechnung der Kosten von Wärmeversorgungsanlagen Raumheizung	Calculate heating load	1993	VDI (1993)
3	Heizkraftwerk Volta	Heat production of heat power plant Volta	2016	IWB (2016a)
	Umweltbericht 2015 der KVA Basel	Heat production of trash power plant	2016	IWB (2016b)
	Jahresbericht 2014	Heat production of wood fueled power plant	2015	AG (2015)
	Durch Raumanalysen das energetische Potenzial von Abwasser heben	Estimate temperature of wastewater	2015	Knies (2015)

	Jahrestabellen Temperatur 2014, Rhein - Weil, Palmrainbrücke	Temperature river Rhine	2016	BAFU (2016a)
	Jahrestabellen Abfluss 2014, Rhein - Rheinfelden, Messstation	Flow rate river Rhine	2016	BAFU (2016b)
4	-	-	-	-
5	-	-	-	-
6	IWB Trinkwasser - Das kostbare Lebenselixier	Map of freshwater network	2015	IWB