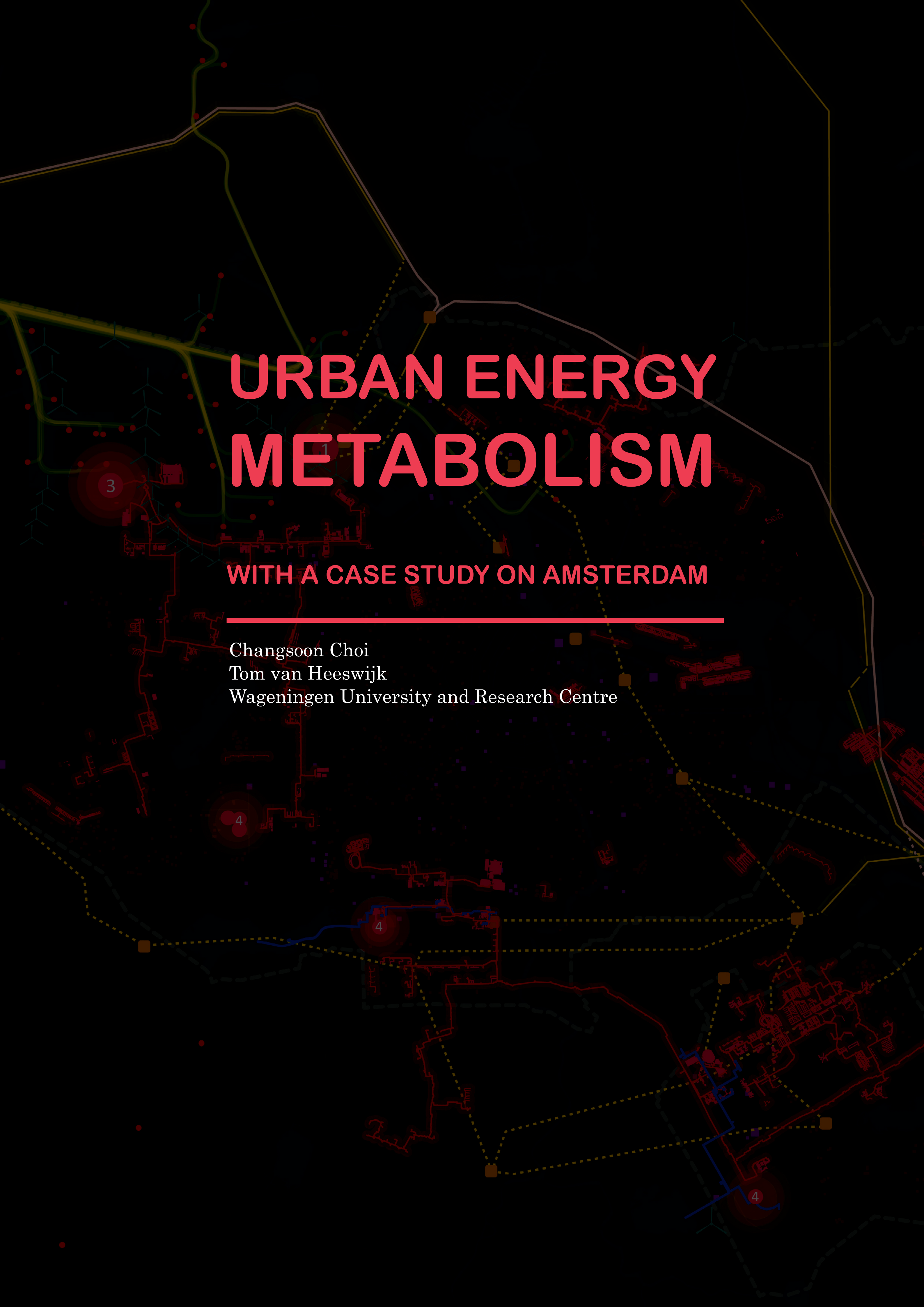

URBAN ENERGY METABOLISM

WITH A CASE STUDY ON AMSTERDAM

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Wageningen University and Research Centre

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Preface

Dear reader,

this minor thesis report is part of the master Landscape Architecture and Planning, specialisation Landscape Architecture at Wageningen University. This minor thesis took place in the first semester of the academic year 2014-2015, and with relations to the URBAN PULSE project commissioned by AMS (Amsterdam Metropolitan Solutions).

The minor thesis is about energy, a topic that was new for us and of which we did not have experience yet. It was an interesting and especially instructive period for the both of us. Although we faced many challenges because we found ourselves on unfamiliar territory, we found it an interesting topic to learn from. Also because we extended our skills with this topic as prospective landscape architects.
We want to thank Sven Stremke and Ilse Voskamp for their supervision.

Tom van Heeswijk   Changsoon Choi

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Abstract

Since the industrial revolution, fossil fuels became a fundamental resource that would sustain human societies. Considering energy, many cities today represent a linear urban metabolism whereas fossil fuel resources are for the most part imported, and used inefficiently. Large outputs of waste are disposed. Greenhouse gas emissions as a consequence stimulate disastrous effects of global warming. Additionally the depletion of fossil fuels forces us to seek alternatives. Therefore a more effective urban energy metabolism driven by renewable energy assimilation is needed. This report offers energy-conscious strategies for urban planning that are able to improve an urban energy metabolism. Amsterdam is used as a case study whereby it's energy metabolism is analysed in order to illustrate how energy-conscious strategies could improve a city's energy metabolism in practice. Therefore an example of an often missing link between urban metabolism and energy-conscious spatial planning is made. The study consists of two parts: a literature study and a case study. A literature study was conducted on two subjects: urban metabolism and energy-conscious concepts and strategies. The energy-conscious concepts and strategies are identified and framed by urban metabolism concepts. Subsequently, a case study on Amsterdam is conducted based on the Urban Harvest Approach of Leduc and Van Kann (2013). This method exists of five steps: (1) land-use inventory, (2) energy demand inventory, (3) local energy potential analysis, (4) energetic linkages analysis, and (5) exploration of network patterns. The method is applied on metropolitan scale: the municipality of Amsterdam. Step 6 is illustrated by energy-conscious strategies for Amsterdam, and is based on energy-conscious strategies framed by urban metabolism and the case study. Various energy-conscious strategies gained a ranked relevance for improving 3 metabolic components: input, output and internal processes in a city's energy metabolism, reaching an optimized linear metabolism. Having Amsterdam used as a test case, illustrated paths of achieving a sustainable urban energy metabolism can contribute in increasing sustainability of cities.

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All the contents in the thesis were basically discussed and finished together. Generally Changsoon Choi was responsible for the theoretical parts such as the literature study, while Tom van Heeswijk was responsible for the more practical parts such as the case study. However, in making this report, tasks are distributed separately to be equivalent for each other as following:

Tom van Heeswijk was responsible for chapter 1 'Introduction', chapter 3 'Methodological framework', chapter 5 'Case study analysis', chapter 6 'Energy-conscious strategies Amsterdam', Abstract, Appendices 1-5 and Conclusions.

Changsoon Choi was responsbile for chapter 2 'Theoretical framework', chapter 4 'Literature study', Appendix 6 and Discussion.

Chapter 1, 2 and 3 were largely based on the research proposal written together, but gained improvement throughout the process. Decisions for representing Chapter 6 were made together as well.

1. INTRODUCTION

1.1 Problem context

1.1.1 Energy

Although energy is difficult to grasp, energy is integrated in our environment, it thrives our society. Whether energy is used for heating a room, illuminate a street, taking care of a warm shower, or making dwellings able to cook dinner, energy is nowadays indispensable.
But what is energy? Although many interpretations can be given to it, we consider energy in this minor thesis as a quantitative measure that has the ability to perform work (Dincer and Cengel in Stremke et al., 2011). In this perspective, energy can exist for example of electricity, thermal energy (heat and cold), and fossil fuels such as coal, oil and natural gas. These types of energy are commonly used in our contemporary society whereas they fulfil tasks, they are able to perform work. However, fossil fuels for transport and electricity generation will constitute prospective problems.

1.1.2 Prospective problems

The availability of conventional energy resources such as oil and gas is decreasing. In the Netherlands the largest part of energy consists of fossil fuel energy, from this fossil fuel energy the largest part is imported (Ptasinski et al., 2006). Imported energy increases dependency on foreign (and unpredictable) economies which cannot be considered sustainable (Stremke, 2008). Another disadvantage of fossil fuels is their greenhouse gas (GHG) emissions that increase the effect of global warming. Rising sea levels, changing temperatures and changing precipitation are constituted by global warming (Stremke, 2008). In the Netherlands, winters will become more wet, rain showers will get heavier in shorter durations of time, and an expected rising sea level will cause low-situated areas to flood (Hurk et al., 2014).

Considering energy generation in the Netherlands still relies on fossil fuels for the most part, emphasis on using renewable energy locally rather than fossil fuel-based energy has three major advantages:
1. Overcoming depletion of fossil fuels;
2. Reducing GHG emissions from energy generation and transport, therefore counteracting climate change;
3. Minimizing dependency on foreign economies.

A transition to renewable energy is needed to prevent a situation with complete depletion of fossil fuels lacking alternative resources (Stremke and Koh, 2010). Most policies of Dutch cities do not address transition to renewable energy in order to achieve a sustainable city (Stremke, 2009). Considering the described problems of: depletion, dependency on foreign economies and increasing global warming, our society has to make the step towards a renewable energy system in order to provide a stable future. A renewable energy system is “a system that utilizes renewable energy sources and recycles materials effectively” (Stremke and Koh, 2010).

1.2 Problem description

Framed by the problem context, the problem description addresses more specifically the problem that will be addressed in this report.

1.2.1 Ambition of Amsterdam

According to the ambition document "De Circulaire Metropool Amsterdam 2014-2018" ("The Circular Metropolis Amsterdam"), the municipality of Amsterdam desires to have in 2040 75% less CO2 emission on a yearly basis compared with 1990. In 1990 the municipality of Amsterdam emitted 3.420 kiloton CO2 per year (Zwijnenburg and Bosman, 2014). In 2012 this output raised to 4.580 kiloton CO2 per year (ibid). Amsterdam's target is to have a maximum output of 2.050 kiloton CO2 per year in 2025, and in 2040 the output per year should be 855 kiloton CO2 at most (Figure 1.1). Transition to renewable energy sources is one of the most influential actions that contribute to achieving the desired CO2 reduction (ibid).

The underlying motivation for this target is that fossil-fuel based resources become more scarce, therefore prices of these resources are rising, and gaining these resources cost more money and energy (ibid). If the business as usual (BAU) scenario continues, inhabitants of Amsterdam will have to pay for increasing energy costs. The other reason for the reduction target is counteracting climate change. Explained in the ambition document, Amsterdam also strives for a more circular city: which means local generation of renewable energy with as many closed cycles as possible. Closed cycles in terms of energy occur when residual or un-used energy is stored and re-used, rather than disposing. Because Amsterdam's CO2 reduction target proposes local renewable energy generation along with closed cycles, it complements the problem context in minimizing dependency on foreign economies.

Figure 1.1 Ambition of CO2 reduction in 2025 and 2040. Source: Zwijnenburg and Bosman, 2014)

1.2.2 Urban metabolism as approach for Amsterdam's ambition

Amsterdam can be considered as a metropolitan urban area, it deals with energy flows existing of certain energy inputs, energy flows within the city, and energy outputs. These three items are strongly related with the concept of 'urban metabolism'. Considering this minor thesis focusses on the flows of energy, urban metabolism is considered as an appropriate concept that provides methods for analyzing flows of energy, as well as flows of food, water and materials in a city (Baccini, 1997; White, 2002; Kennedy et al., 2011; Zeman, 2012). Briefly, the concept of urban metabolism considers cities as living ecosystems with their own metabolism in terms of its exchanges of matter and energy constituted by urban socio-economic activities (Pincetl et al., 2012).

Thus, urban metabolism can provide answers for the question on how to achieve Amsterdam's ambition for a more circular city, driven by renewable energy with reduced CO2 emissions. The concept of urban metabolism will be further elaborated in Chapter 2 and 4.

1.3 Purpose statement

The purpose statement explains the knowledge gaps and the research objective that gives answers to the knowledge gaps. Two knowledge gaps were identified.

1.3.1 Knowledge gaps

1. Missing link between urban metabolism and energy-conscious planning and design

Although they are related, there is no explicit cooperation between urban metabolism and energy-conscious planning and design. Studies of urban metabolism with a spatial perspective have only been conducted recently with a few researches (Tillie et al., 2014). Mostly when a city's urban metabolism is analysed, there is no link towards the final 'end-users' who actually can improve the environment such as urban planners, (landscape-) architects and engineers (Kennedy et al., 2011; Chrysoulakis et al., 2013).

2. Amsterdam's lack of analysis and strategies for its urban metabolism regarding the energy issue.

Since Wolman (1965) was the first to analyse a city's metabolism, many cities have been analysed on their urban metabolism with regards to the cities' sustainability (Kennedy et al., 2011). Currently Amsterdam has the ambition to become a sustainable city. However, Amsterdam has not established yet an up to date analysis of, and strategies for its urban metabolism regarding energy flows. Therefore, energy-conscious strategies for improving Amsterdam's urban metabolism can form the link towards a concrete vision for the city that goes beyond the ambition document.

1.3.2 Objective

The objective of this research is to identify concepts and strategies for a sustainable urban metabolism, with the focus on energy. This study will reveal generic energy-conscious concepts and strategies that are framed by the concept of urban metabolism. These concepts and strategies can be applied for cities in general. Using Amsterdam as a test case, this study also illustrates which of the generic strategies are applicable for Amsterdam, based on an energy-focused analysis of the city.

Concepts are abstract ideas that describe how phenomena work (Waters and Bull, 2007). Before strategies are elaborated, concepts are able to offer common understanding about phenomena considered by the strategies. Strategies are therefore the actions of planning how to do or achieve a long-term aim or overall aim, and are therefore prescriptive (Waters and Bull, 2007). In this minor thesis multiple strategies are shown that together achieve the overall aim towards a sustainable urban metabolism with the focus on energy.

1.4 Relevance

In the context of rapid urbanization and aim for sustainable development, the city of Amsterdam launched the Amsterdam institute for Advanced Metropolitan Solutions (AMS). AMS, cooperating with Wageningen UR, TU Delft, and MIT, deals with challenges of sustainability and quality of life in a city. AMS aims to explore urban design and technology to resolve, steer, and navigate city flows of energy, water, food and waste by means of urban metabolism (AMS, 2013). Sven Stremke from NRGlab at Wageningen UR participates in the AMS as a Principal Investigator for energy. AMS organized an assignment called URBAN PULSE whereas knowledge for sustainability strategies concerning energy, water, food and natural resources is being generated. Supervised by Sven Stremke, this minor thesis therefore contributes to the URBAN PULSE project with the focus on energy.

1.4.1 Landscape architectural relevance

Landscape architectural relevance is warranted because this study aims to provide landscape architects and urban designers with relevant concepts and strategies of urban energy metabolism that can be used for further practices or researches. Considering growing interests in energy-conscious planning and design in the spatial-related disciplines, the result of this thesis can benefit professionals and academics while planning and designing sustainable (urban) energy landscapes.

1.4.2 Academic relevance

The concept of urban metabolism for understanding urban systems is already researched (Baccini, 1997; Kennedy et al, 2010) but further spatial implications in making sustainable cities in terms of energy are rarely studied. Tillie et al. (2014) and Sijmons et al. (2014) prescribe steps for spatial implications regarding urban (energy) metabolism. This thesis aims to address this knowledge gap as well in order to expand studies about planning renewable energy with a spatial perspective.

1.4.3 Social relevance

This study will have a social significance in that, according to the ambition document of Amsterdam's CO2 reduction, the city of Amsterdam stresses that energy transitions towards renewable sources and its spatial implications are inevitable. We conduct this research to offer directions to support renewable energy transitions and carbon neutrality of Amsterdam, contributing to a healthy living environment for its inhabitants.

1.5 Guide for the reader

This report is structured in seven chapters. Chapter 1 explained the problem statement and motive for this research. The objective as a purpose of the research is briefly explained, as well as its relevance. Tom van Heeswijk was responsible for Chapter 1.

In chapter 2 'Theoretical framework', two fundamental concepts are elaborated in order to provide the reader essential information contributing to understanding the sequel of the report. These two concepts are 'sustainable energy landscape' (SEL) and 'urban metabolism' (UM), together forming the theoretical framework. Changsoon Choi was responsible for this part.

Chapter 3 'Methodological framework' elaborates the research questions, research strategy and methods that can bring answers to the research questions. The research questions are based on the objective mentioned in chapter 1. Two methods are elaborated: a literature review for the theoretical part and a five-step approach for the analysis part. Tom van Heeswijk was responsible for this part.

A literature study relevant for energy-conscious concepts and strategies as well as urban metabolism is elaborated in chapter 4. The literature study concludes important findings and aims to relate urban metabolism with energy-conscious concepts and strategies. Chapter 4 was written by Changsoon Choi.

The case study in chapter 5 shows the analysis of Amsterdam's energy consumption and renewable energy potentials, using the city as a test case to identify inefficiencies and potentials when it's urban (energy) metabolism should be improved. Amsterdam's energy system is analysed, and finally an analysis of the city's energy consumption and renewable energy potentials are shown. Eventually findings about Amsterdam's energy utility are elaborated, which are fundamental input for Chapter 6 'Energy-conscious strategies for Amsterdam.'

Chapter 6 illustrates which energy-conscious applied strategies can improve Amsterdam's urban (energy) metabolism in terms of renewable energy, energy flows and energy consumption. Therefore chapter 6 illustrates how energy-conscious strategies can inform future implementation. Tom van Heeswijk was responsible for Chapters 5 and 6.

Finally chapter 7 addresses 'Discussion and conclusions'. In the discussion questions and findings aroused during the study will be critically discussed. Also suggestions for further research are addressed. In the conclusions essential findings of this study are summarized, aiming to give answers to the research questions. Subsequently this study is being put in a global perspective, examining how it can contribute in improving a city's urban (energy) metabolism. Discussion and Conclusions were written together, whereas Changsoon Choi was responsible for Discussion and Tom van Heeswijk for Conclusions.

2. THEORETICAL FRAMEWORK

This study concerning urban metabolism is inspired and based on the ongoing researches on sustainable energy landscapes, with the context of sustainable energy systems (Stremke, 2010). In this study, sustainable energy landscapes are understood as a part of several sustainable energy systems in achieving sustainable energy transitions (see, e.g. Stremke, 2010). These notions of sustainable energy landscapes form the basis of the study together wih urban metabolism concept.

2.1 Sustainable (urban) energy landscapes

Sustainable energy landscapes are defined as "landscapes that are well adapted to renewable energy sources without compromising other landscape services, landscape quality or biodiversity" (Stremke 2010, p.1). Although the term 'landscape' embraces urban and rural areas, urban areas are of importance in the concept of landscape in this thesis as the thematic scope of the study concerned with urban metabolism. With the topic of sustainable energy landscapes, concepts and strategies from the domains of ecology and thermodynamics are explored with the relevance to energy-conscious spatial planning and design (Stremke and Koh, 2010; Stremke et al., 2011). These concepts and strategies support us to explore the energy-related concepts and strategies with the perspective of urban metabolism. .

Sustainable energy transition

In a renewable energy transition, "research must focus on a system approach to the entire (energy) chain, from primary sources of energy to end-user"(KNAW, 2007, p.xiii). In this context, sustainable energy transition refers to a shift to from fossil fuel based energy systems to sustainable energy systems (Stremke and Dobbelsteen, 2012). However, sustainable Energy Transition is not limited to a transition toward renewable energy sources, but also requires efficient use of energy (Stremke and Koh, 2009).

Sustainable energy systems

A sustainable energy system refers to "a cost-efficient, reliable, and environmentally friendly system that effectively utilizes local resources and networks" (Hepbasli, 2008, p.598). Researchers studied principles and strategies to increase the sustainability of energy systems (See, e.g. Dobbelsteen, 2008; Lysen, 1996).

2.2 Urban metabolism

Similar to human metabolism or cyclical mechanisms of natural ecosystem, the physical and biological systems of a city require fluxes of materials and energy for transforming products, services, and subsequently generating wastes (Huang and Hsu, 2003). In this sense, cities can be considered as as living organisms or ecosystems (Pincetl et al., 2012). In the paper "The Changing Metabolism of Cities", Kennedy et al. (2007) defined urban metabolism as "the sum total of the technical and socio-economic process that occur in cities, resulting in growth, production of energy and elimination of waste" (Kennedy et al., 2007, p.44). With the context of rapid urbanization and concern for climate change, urban metabolism has emerged as an important concept in understanding urban systems quantitatively and proving insights for sustainable development (Ferrao and Fernandez, 2013; Kennedy, 2010).

In the discourse of urban metabolism concerning sustainable development, a linear model of metabolism is considered problematic, unbalancing ecosystem as resources are produced, consumed, and then disposed to the environment (Giradet, 1992). Thus, shifts to a more effective model of metabolism in cities are required for sustainable urban development where outputs are recycled and reintegrated into the system (Girardet 2008) to increase the efficiency of resources and avoid waste (Newman, 1999).

In our thesis the concept of urban metabolism, specifically the environmental school of UM studies, is focused as a theoretical framework since the school focuses on the implications of urban metabolism on urban areas (Rapoport, 2011). Thus, the urban metabolism approach provides both descriptive and prescriptive insights by studying an assessment tool for a city's energy system, urban metabolism concepts and its deriving strategies. The environmental UM school has discussed two main research approaches: 'the city as an ecosystem' and 'material and energy flows in the city' (Broto et al., 2012).

The city as an ecosystem

The idea of the city as an ecosystem is applied mostly in the field of industrial ecology and urban ecology (Marcotullio and Boyle, 2003). It focuses on applying the metabolism concept to the urban area with its possible implications by studying concepts from natural ecosystems (Girardet 2008; Newman and Jennings 2008; Niza et al., 2009). Thus in our thesis, the concept of urban metabolism provides normative insights on how to improve a city's energy metabolism by framing identified various energy-conscious strategies with urban metabolism models. This results in the energy-conscious strategies with a relation to urban metabolism and specific exemplary strategies for the case of Amsterdam.

The city as material and energy flows

This study generally focusses on examining the flow of materials and energy in an urban system (see, e.g. Barles, 2010; Baccini, 1997; Brunner, 2008). The studies on material and energy flows in the city provide this study with an assessment tool in quantifying cities' energy flows. This part of thesis can be seen in the literature study (Chapter 4) and is also applied in the case study of Amsterdam.

2.3 Conclusions

Natural ecosystems and human ecosystems have similarities (Nielsen, 2006 and Korevaar, 2007 in Stremke, 2010, p.5). According to Stremke, ecological concepts have inspired and thus applied for spatial planning and design (e.g. McHarg, 1969; Hough, 1984; Lyle, 1994). In that sense, urban metabolism and sustainable energy landscapes have many things in common. They both are the approaches in achieving sustainable development based on concepts from natural ecosystems (e.g. Stremke and Koh, 2010; Stremke et al., 2011; Wolman, 1965). Considering the increasing importance of a transition to sustainable energy systems with renewable energy in cities, urban metabolism can give insights on how to understand and also improve current (fossil-fuel based) urban energy systems into sustainable energy systems in developing a sustainable energy transition. Thus, combining the concepts of sustainable energy landscapes with urban metabolism, substantial knowledge for urban (energy) metabolism (Figure 2.1) can be made and tested with a case study of Amsterdam.

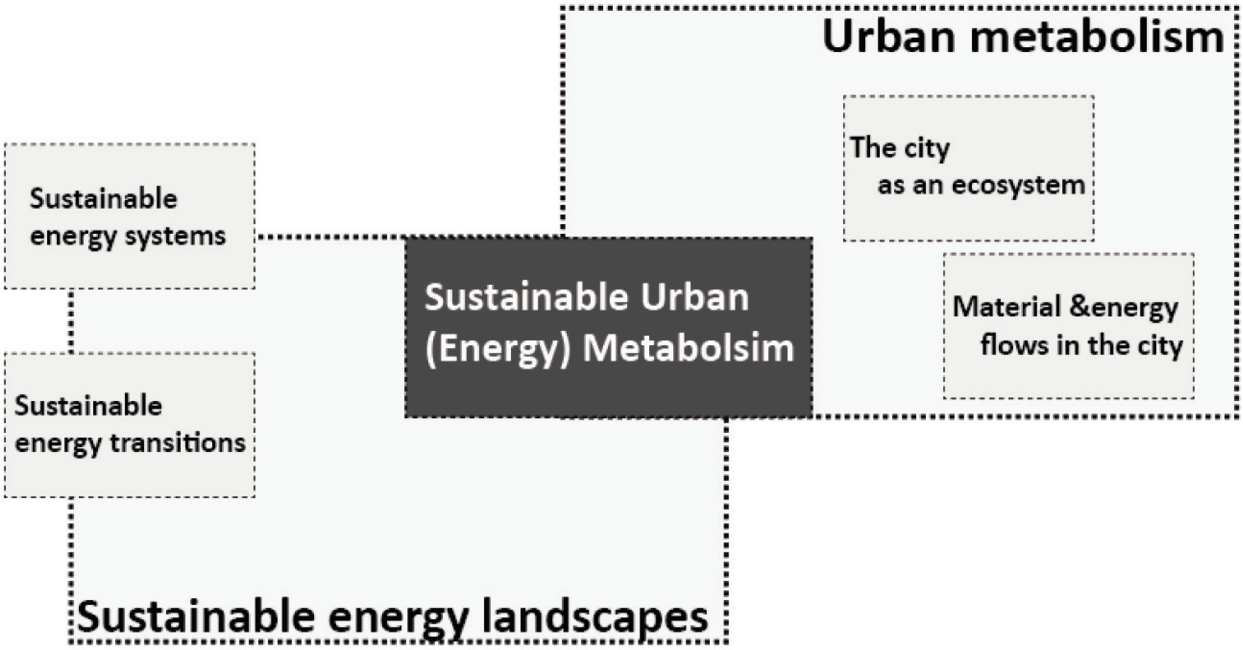


Figure 2.1 Conceptualized theoretical framework.

3. METHODOLOGICAL FRAMEWORK

This chapter elaborates the structure of the research. First the central research question is stated with the sub research questions. Subsequently the research strategy is elaborated, assisted by the chosen methods that can give answers to the research questions.

3.1 Research questions

The objective (paragraph 1.3.2) is translated into a main research question. The central research question forms the basis for this research. Three sub research questions help to search for findings that can answer the main research question.

Main research question
Which concepts and strategies for sustainable urban (energy) metabolism have been described in the literature and which ones are applicable to the transformation of the urban metabolism in the city of Amsterdam spatially?

Sub research question 1
Which concepts and strategies for sustainable urban (energy) metabolism are described in the literature with spatial relevance?

Sub research question 2
How does the current urban (energy) metabolism of Amsterdam work and how can it be represented?

Sub research question 3
Which strategies for sustainable urban (energy) metabolism can be applied to Amsterdam's case?

3.2 Research strategy

Energy-conscious strategies related with urban metabolism are addressed with both qualitative and quantitative research. Figure 3.1 shows the process of the minor thesis. The research is conducted in three steps. First a literature study is performed in order to cover the range of energy-conscious strategies, and to discover how those strategies related with urban metabolism can improve a city's urban energy metabolism. Secondly a case study is performed addressing Amsterdam's urban energy metabolism. The case study exists of a desk research based on GIS map data and secondary quantitative data, whereas its findings will reveal inefficiencies and potentials that need to be addressed when improving Amsterdam's urban energy metabolism. Finally a desk research is conducted for identifying energy-conscious strategies for Amsterdam. This last step uses the first two steps as fundamental input.

3.3 Methods

3.3.1 Methodology first phase

A literature study is conducted on two subjects:
- energy-conscious concepts and strategies;
- the concept of urban metabolism.

For the literature study, a systematic literature review is used to conduct an objective and transparent approach for literature review, with minimized bias

(Gatrell et al., 2005). The systematic literature approach is performed through several steps (ibid).

Literature review on energy-conscious concepts and strategies

For the literature review of energy-conscious concepts and strategies, the first step is to form populations through the database or search engine. Populations of 332 documents are formed with defined key terms in their titles, abstracts, and/or keywords through a web-based scholarly articles search engine called Scopus. In Scopus the following key words were entered on 10 October 2014 resulting in 332 found documents:

energy OR “energy landscape” OR “sustainable landscape” AND “spatial planning” OR “urban planning” OR “urban design” OR architecture OR “landscape architecture” AND principles OR strategies OR concepts

Then, in order to form a relevant sample, the populations are distilled with the inclusion and exclusion criteria as a sampling frame: which includes the timeframe of fifteen years from 2014, language use of English, and excluding categories of Chemical sciences, Computer sciences, and Medicine. For the sampling strategy, judgmental sampling is used to examine the document’s relevance to the research topic (Deming and Swaffield, 2011) through scanning of abstracts. As a result, 25 journal articles out of 332 found documents were identified as a first sample.

Since energy-conscious concepts and strategies gradually became an important topic these days, ‘grey’ literature is added next to the reviewed and published scholarly articles. The found literature at this stage is not the complete list of literature, but has evolved through a snowballing strategy within the identified body of literature until the amount and quality of the found knowledge reached a saturation point (Kumar, 2005). 51 documents formed the final sample. Grey literature exists for example of energy master plans for cities, papers or presentations posted on web-sites, or books exploring spatial implications based on energy-conscious ambitions. In total 51 documents were selected.

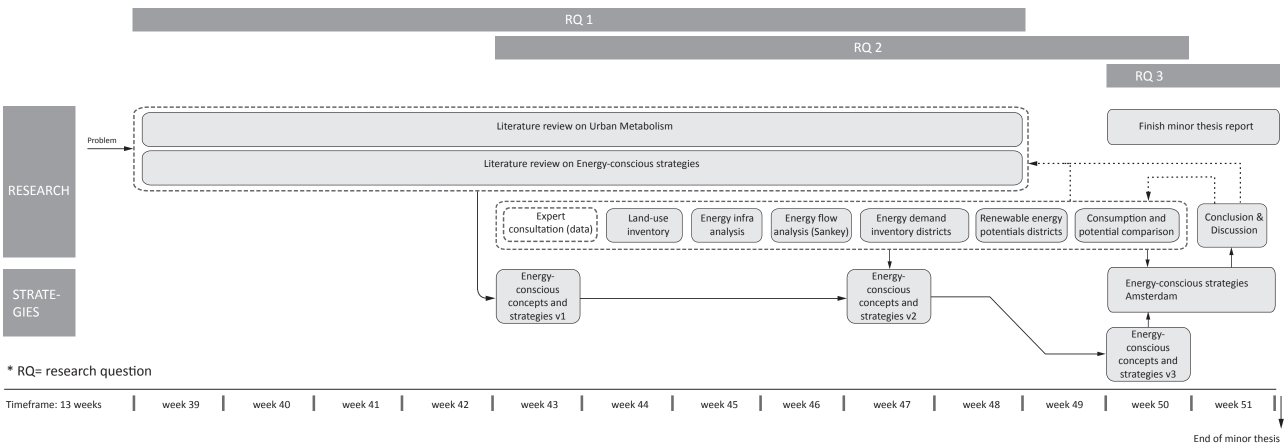


Figure 3.1 Flowchart of the minor thesis process. A literature review and a case study had to be conducted simultanesousoly, therefore tasks described in the Table of Contents and paragraph 1.5 ‘Guide for the reader’ were distributed from week 42. There was however always development in both parts from both authors.

Literature review on urban metabolism
For the grasping the concept of urban metabolism, a literature search is conducted with the key term of "urban metabolism," in article's titles, abstracts, and/or keywords through Scopus. On 8 October 2014, 248 documents were found. Then, a judgmental sampling is used as a sampling frame to select relevant literature from the 248 documents (Deming and Swaffield, 2011). In this sampling phase, considering the research questions of this thesis, urban metabolism studies with a spatial perspective in an environmental school gained more focus than the studies with qualitative approach in a sociological school. Eventually 31 out of the 248 documents were selected to read. Additionally a snowballing sampling strategy is performed, whereas literature of urban metabolism not included in the 248 found documents but considered as valuable input is identified as a sample. In addition to peer-reviewed articles, grey literature is extensively considered to ensure the diversity of literature, such as the urban metabolism study published during the IABR 2014 (Tillie et al., 2014). In total 46 documents were selected.

Continuation after literature selection
In the next step the selected literature is summarized and reviewed. The literature is put in a conceptual way so that an appropriate body of knowledge is organized. In this step the literature is summarized with the author's own words.

Subsequently the summarized concepts and strategies with the perspective of urban metabolism resulted from the literature study on urban metabolism were analysed and categorized. The structure in this phase is to categorise each strategy framed by the important theoretical components of urban metabolism.

The last step is to narrow down the scope of analysed concepts and strategies to form a generic list of strategies with spatial relevance that are able to achieve a sustainable urban (energy) metabolism. A strategy is considered to have spatial relevance when it carries consequences for spatial planning and design. This occurs when physical changes in the (urban) landscape are required to be made. It provides a link for the next research phase (sub-paragraph 3.3.2) so that the review has a logical structure (Carnwell and Daly 2001).

3.3.2 Methodology second phase

After defining generic concepts and strategies with spatial relevance from the first phase (literature review), strategies applicable for Amsterdam for achieve an improved urban (energy) metabolism were identified. These strategies illustrate how theory could be applied in practice, in order to develop the body of knowledge that concerns achieving ambitions with a sustainable energy transition and urban metabolism as a starting point.

Leduc and Van Kann (2013) state that most cities contain a linear urban metabolism with big amounts of input and waste (Leduc and Van Kann, 2013, p.182). They propose a methodology for energy-conscious planning and design to identify strategies for a more effective linear metabolism. A methodology of five steps is now elaborated, partly based on that of Leduc and Van Kann (2013).

1. Land-use inventory
As a first step it is important to have a general impression of the particular site with reduced complexity. Residential areas, industrial areas, and business areas are categorized, as well as non-

built-up areas (e.g. water, agriculture and forest/green). Percentages of different types of land-use (e.g. residential terrain, park and company terrain) are derived from 'Amsterdam in Cijfers 2013' (Bureau Onderzoek en Statistiek, 2013). For the land-use, ArcGIS and ArcMAP were able to provide map data. This part is shown in paragraph 5.1.

An additional inventory in terms of land-use is conducted about Amsterdam's energy infrastructure. This inventory is not part of the methodology from Leduc and Van Kann, but was needed to reveal how the current energy system is situated. The infrastructure mapped consists of high voltage power lines, power plants, thermal networks, wind turbines, locations of solar PV and thermal storage points. This part is shown in paragraph 5.2.

2. Energy demand inventory

Firstly, a Material Flow Analysis (MFA) in terms of energy concerning the municipality as a whole is conducted, and represented by a Sankey diagram (paragraph 5.2.2). This step is also not part of the methodology of Leduc and Van Kann, but was needed to identify inefficiencies and potentials in Amsterdam's current energy balance. The MFA reveals which quantified types of energy enter, leave and are being consumed in Amsterdam on a yearly basis.

To identify energy consumers more specifically, low-demanding and high-demanding districts were mapped. Energy consumption of districts is shown in paragraph 5.3. In the energy consumption, electricity, gas and transport fuels were considered. Data about energy consumption are for the most part collected from Klimaatmonitor databank (Rijkswaterstaat, 2012), CBS statistics and a CO_2 emission report (Klimaatbureau Amsterdam, 2011).

3. Local renewable/residual energy potential analysis
Local potentials can reveal what the particular site has to offer concerning energy generation, and if imported resources are then still needed when the current energy demand is considered. It is shown in paragraph 5.3. A local potential map also hosts guidance for locating renewable energy generation (Leduc et al., 2009, p.7). The organizations DRO of Municipality Amsterdam, Nuon, Alliander, TNO, TU Delft and other contributors composed an Amsterdam Energy Atlas (den Boogert et al., 2014). This document shows where high and low potentials of various renewable energy sources are located within municipality borders of Amsterdam. Important to mention is that the Energy Atlas was fundamental in collecting data about renewable energy potentials.

4. Energetic linkages analysis
With the energy consumption inventory from step 2, and local energy potentials from step 3, analysis of energetic linkages reveal insufficiencies and opportunities in sub-paragraph 5.3.4. Insufficiencies are in this case exergetic gaps: shortcomings of exergy- delivery or demand. Concerning an exergetic gap in delivery, additional energy supply is required. And concerning an exergetic gap in demand, additional functions should be implemented that consume all remaining energy in order to reduce energy waste. The result of this step is a map that shows city parts with theoretical ‘shortages’ and ‘surpluses’ of energy in a hypothetical situation where Amsterdam fully relies on renewable energy.

5. Exploration of network patterns
This step is conducted to show how spatial clusters can be connected and how to reach a more effective energy metabolism (Leduc and Van Kann, 2013, p.186). This final step exists of identifying energy-conscious strategies applied for Amsterdam, and is shown in Chapter 6. It is based on all four previous steps as well as the literature study from the first phase of the methodology.

4. LITERATURE STUDY

The study in this thesis benefited mainly from the literature in both urban metabolism and energy-related topics in environmental design fields. Thus, the literature discussion below is divided into two topics: (1) urban metabolism and (2) energy-conscious concepts and strategies.

4.1 Urban metabolism

4.1.1 urban metabolism approach

In the context of rapid urbanization globally and limited amounts of resources, cities are facing serious environmental problems and struggling to achieve the goal to become sustainable cities (Zhang, 2013). The concepts from ecology and biological science have influenced the discourses on sustainable urban development (Broto et al., 2012). Urban metabolism is such an interdisciplinary concept that has inspired a new approach in achieving sustainable cities by understanding complex urban systems based on ecological concepts and methods (see, e.g. Wolman, 1965; Girardet, 1992; Baccini, 1997; Tjallingii, 2003; Odum, 1983). The concept of urban metabolism (UM) refers to the exchange processes of material and energy through cities (Decker et al., 2000). It considers cities as living organisms or (human) ecosystems in a biological sense (Rapoport, 2011) and examines the balance of a city's resource inputs (e.g. fuel and raw materials) and outputs (e.g. CO_2 emissions and wastes) (Newman 1999).

In a natural ecosystem, materials and energy are assimilated from resources as input and consumed, subsequently generating wastes as output. Understanding this metabolic relationship of material and energy in a natural ecosystem is essential in urban metabolism studies (Zhang, 2013). The understanding of cycling mechanism in a natural ecosystem has been applied for cities to understand different metabolic flows such as food, water and energy quantitatively (Zhang, 2013). Also, this understanding has provided insights for environmental planners and designers so that they can develop directions and models for achieving sustainable developments (Broto et al., 2012).

4.1.2 Interdisciplinary studies on urban metabolism

The metaphor of a city as a living organism or ecosystem with metabolism was first mentioned by Karl Marx in in his book 'Capital' (Marx, 1981) that has been improved by political geographers and ecologists recently (Rapoport, 2011). However, urban metabolism has really been recognised as a branch of science in the several decades from the field of industrial ecology. In the seminal paper of Wolman (1965), he developed the idea of urban metabolism as a method to analyse a city by quantifying input and output of materials and energy flowing into a system like organisms consuming resources such as food (Wolman, 1965). After Wolman's introduction of a platform for discussing resources quantitatively, the majority of urban metabolism studies are the case studies that analyse cities' metabolic functions in the field of industrial ecology, developing assessment methods such as material flow analysis (MFA) and life-cycle assessment (LCA) (see, e.g. Boyden et al., 1981; Sahely et al., 2003; Huang et al., 2006;

Barles, 2009; Decker et al., 2000). Also, some researchers have studied urban metabolism with spatial considerations by considering cities' metabolic exchanges with regards to the spatial organization of land-use (See. e.g., Huang et al., 2006; Idrus et al., 2008; Krausmann et al., 2003; Lee et al., 2009).

Currently, urban metabolism has been studied in various disciplines such as industrial ecology, urban ecology, systems ecology, ecological economics, political economy, political geography, and political ecology (Rapoport, 2011). However, to a certain extent, they can be differentiated with two schools in the scientific fields: an environmental school in the tradition of industrial ecology and urban ecology and a sociological school in the fields of ecological economics, political economy, political geography, and political ecology (Tillie et al., 2014; Rapoport, 2011).

The environmental school of urban metabolism, which is the concern of this thesis, focuses on the metabolic implications on urban areas, supporting the idea that cities should simulate the circular or cyclical mechanisms of natural ecosystems (Rapoport, 2011). Therefore, the urban metabolism concept has provided not only assessment methods in understanding cities, which are descriptive, but also prescriptive insights in guiding sustainable developments (Girardet 2008; Newman and Jennings 2008). This environmental school has been discussed and evolved with two main research themes: 'the city as an ecosystem' and 'material and energy flows in the city' (Broto et al., 2012).

Recently, spatial planners and designers have increasingly discussed urban metabolism with spatial explicit implications (see, e.g. Kennedy et al., 2011; Ibanez and Katsikis, 2014). For example, El Khafif argues the importance of urban metabolism in landscape architecture practices (El Khafif, 2012). This can also be seen by a conference called 'Projective Views on Urban Metabolism' (2014) at Harvard Graduate School of Design, as well as by '2014 International Architecture Biennale Rotterdam-Urban by Nature' with the main theme of urban metabolism (Tillie et al., 2014), and European Community's 7th framework program conducted a research project 'Sustainable Urban Metabolism for Europe [SUME] (2011). The city of Amsterdam launched AMS Institute with the key theme of urban metabolism.

4.1.3 The models for sustainable urban metabolism

The idea of 'the city as an ecosystem' is concerned with a key question "What lessons from the functioning of ecosystems can be applied to design and plan better cities?" (Broto et al., 2012). It has studied ecological concepts from natural ecosystems to explore the nature-inspired models of sustainable urban development (Broto et al., 2012). Natural ecosystems are understood as the sustainable and efficient systems in their use of material and energy with cyclical mechanisms, while urban systems are seen as resource consuming, unsustainable systems with waste generations (Dunn and Steinemann, 1998). When output (i.e. wastes) is not recycled or not properly treated, it gives negative influences on a system and its environment (Girardet, 1992). This model of metabolism is illustrated as a linear metabolism where resources are transformed, consumed, and disposed from a city (Wolman, 1965). The linear metabolism can also be called 'fossil-fuel energy system,' closely related to the types of energy used (Steel, 2008). Based on this knowledge, Girardet proposed a cyclical or circular model of metabolism considering a system or a city as "the black box" (Girardet, 1990). Since the black box model is criticized in that it ignores inner components within the system, majorities of urban metabolism studies today are not limited to the black box model. For example, Zhang et al. suggested a network model within a system (Zhang et al., 2009) (Figure 4.1).

The circular metabolism is generally characterized by the reduced amount of resource inputs, less waste generations as outputs, and the efficient use of resources in a system. The linear and circular metabolisms are illustrated in Figure 4.2. However, the term 'circular' metabolism in terms of energy need to be critically discussed with the exergy concept from the second law of thermodynamic (SLT) perspective. The current circular UM model is reliant on the first law of thermodynamics (FLT) as researchers also mentioned (Newman 1999; Sahely et al. 2003). This ignores the importance of dissipative flows of energy as output. According to the SLT, the quality of energy (e.g. exergy) is decreased during any natural processes although the quantity of energy is always conserved based on the FLT. Therefore, the quantity of energy as input and output should be the same but only their energy qualities are drastically different. In this sense, now the input-output of energy in urban metabolism models should be regarded as those of exergy, and thus the exergy should be utilized as much as possible so that the least of exergy will be dissipated as output. In this sense, energy as output cannot be circulated but only optimized through, for example recycling and reusing exergy during the internal process within a system, and decarbonized through the use of renewable energy sources. Therefore, in achieving sustainable cities from a metabolic perspective, the sustainability of cities in the long term is reliant on a transition from a linear- towards 'an optimized-linear metabolism' as a sustainable urban metabolism model through recycling materials and products back into a system (Newman and Jennings, 2008; Girardet, 2008). This idea of optimized-linear metabolism and exergy concept from thermodynamics will also be discussed in a later section of this chapter and in Discussion. In our

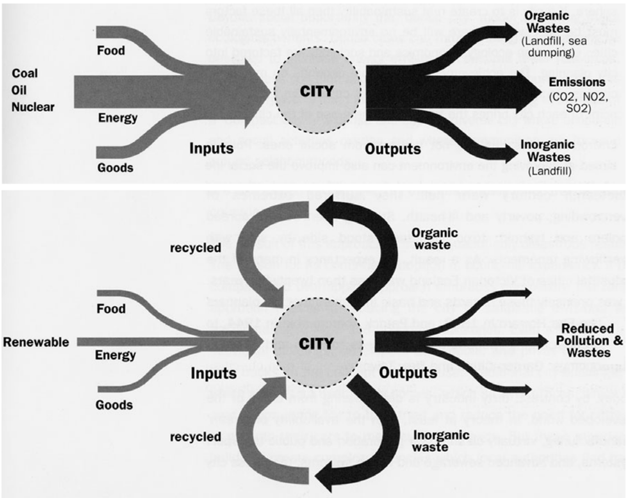


Figure 4.2 Above: a linear metabolism where cities consume and pollute at a high rate and (below) an optimized linear metabolism in which cities minimize input and output and maximize recycling (Rogers, 1997).

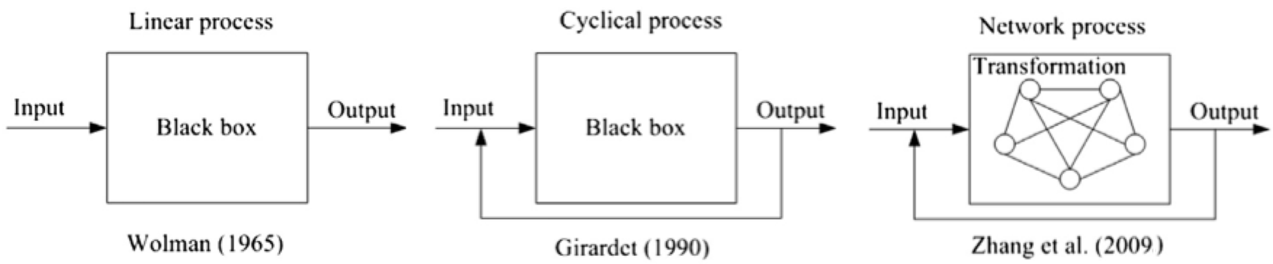


Figure 4.1 The evolution of urban metabolism models (Zhang et al., 2013).

study, the idea of an optimized-linear metabolism is particularly of importance in that it provides insights on the ideal and feasible model of urban energy metabolism. In the case that potential resources were large enough with a small amount of resource burdens, urban activities that are the way of producing and consuming material and energy in a city, had a little influence on the system and its environment (Jelinski et al., 1992). However, today's society with rapid urbanizations and limited resources, for example, the depletion of fossil fuels, the linear pattern of metabolism can be problematic. Contrary to a linear metabolism, system components and their internal process in a system can become closely interrelated each other and thus form the complex networks in an optimized-linear (or previously circular) metabolism (Jelinski et al., 1992; Zhang et al., 2009). In such a system, the in- and outflows of energy and material through a system, for example, from resources and to waste, are reduced (Wachsmuth, 2011; Browne et al., 2009).

4.1.4 Accounting and assessment methods

The research theme of 'material- and energy flows in the city' concerns the question "what methods can account for material and energy flows through the city and can these provide suggestions for their optimization?" (Broto et al., 2012). In the field of industrial ecology, this theme has been studied by conducting comparative analyses of cities quantitatively with regards to their energy efficiency (Broto et al., 2012). The predominant use of urban metabolism these days is to examine and quantify material and energy flows through urban areas (Gandy, 2004). Among assessment methods used in urban metabolism studies, for example,

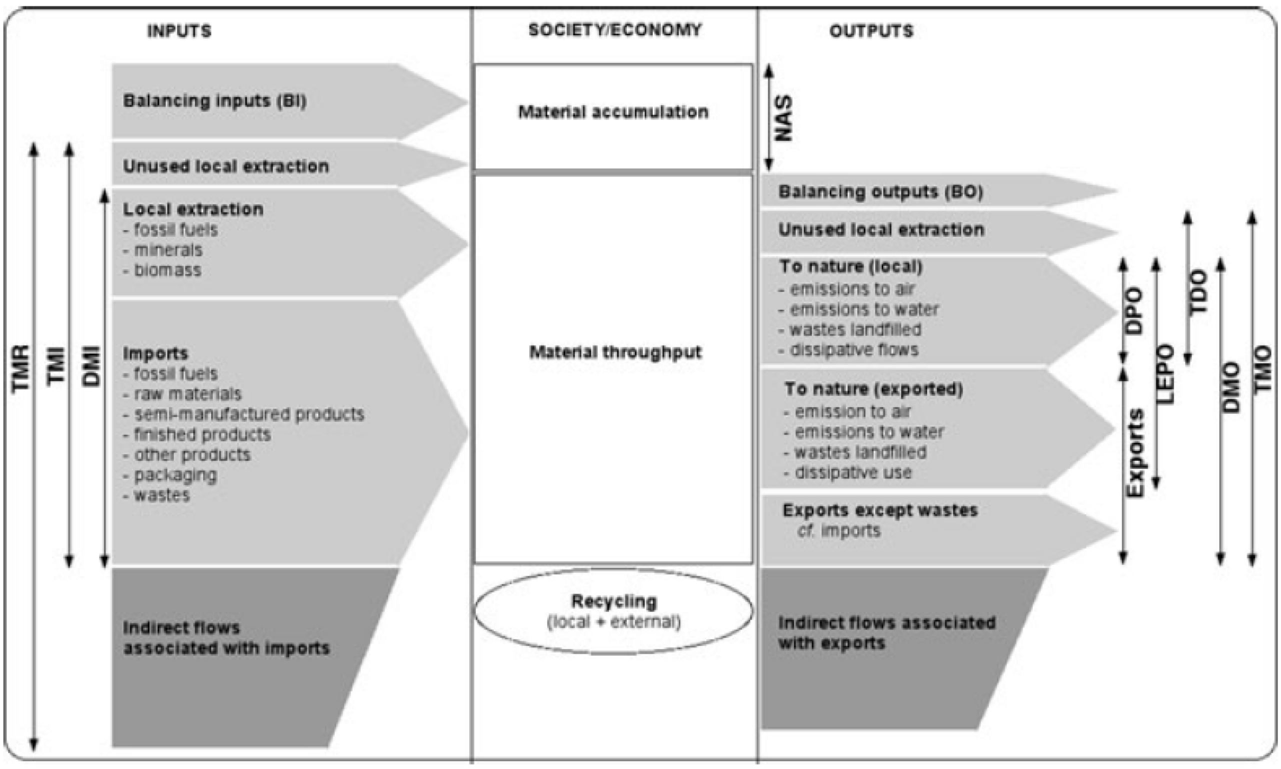
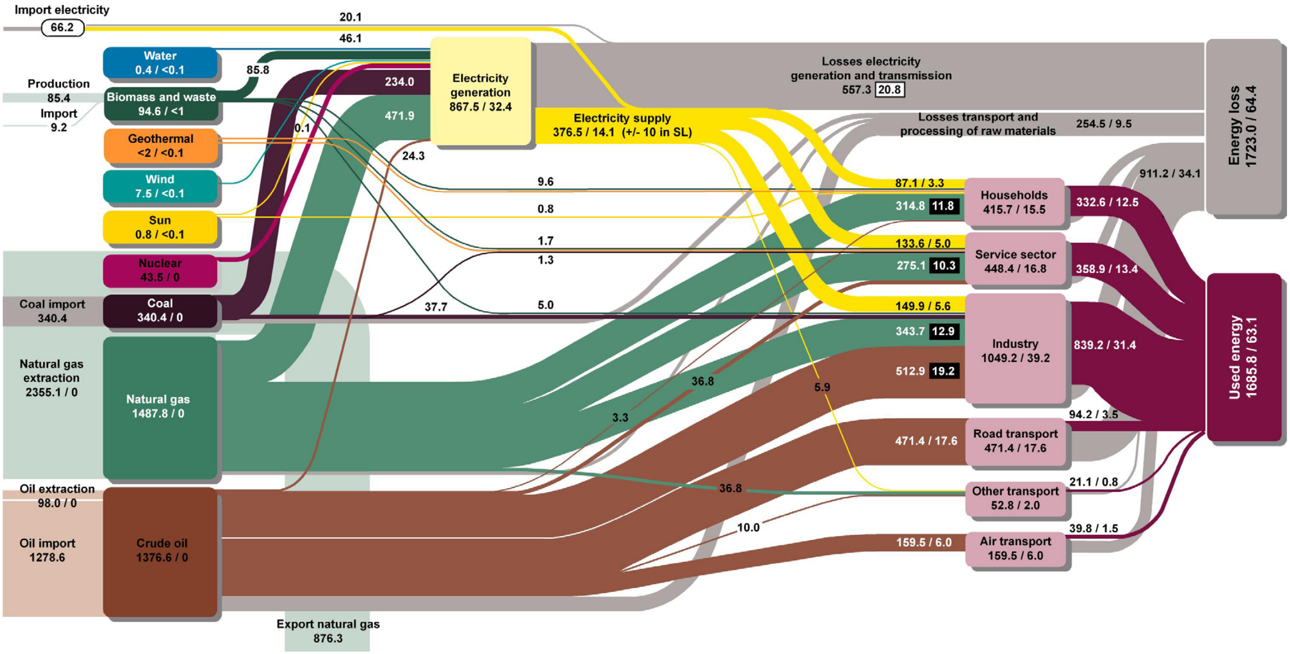


Figure 4.3 An example of MFA describing main flows and indicators (Note: the system is defined by its administrative boundary) (Barles, 2009).



Notes: All numbers in Peta Joule (PJ). First numbers account for the entire Netherlands (e.g. Sun 0.8/<0.1), second number for the region of South Limburg.

20.8 Energy loss due to electricity production and transmission for South Limburg amounts to 20.8 PJ. Residual heat of power plants remains to be utilized.

54.2 South Limburg's share of natural gas and crude oil consumption, primarely for heat production, amounts to 54.2 PJ or approximately 50% of total energy consumption.

Figure 4.4 Sankey diagram of the energy flows in the Netherlands and South Limburg (Stremke and Koh, 2011)

ecological foot print analysis and emergy analysis, and particularly material flow analysis (MFA) has been employed predominantly, leading to the metabolic case studies of cities with MFA (Kennedy et al. 2007; Schulz 2007). Material flow analysis (see example in Figure 4.3) is an effective method to quantify the inputs of material and energy as well as waste outputs within a system, connecting sources, pathways, and sinks of materials (Sahely et al., 2003). In this sense, MFA can provide useful insights to identify environmental problems by identifying inefficiencies and potentials (Browne et al., 2009) as well as to design sustainable cities (see, e.g. Codoban and Kennedy, 2008; Baccini, 1997; Barles 2009; Niza et al., 2009). The result of MFA is generally visualized with the help of a sankey diagram (Figure 4.4). A sankey diagram shows various types of energy flows from sources to sinks with respective thicknesses, representing the amount of each flow.

In discussing metabolism models and its assessment method of MFA, a city's metabolism is generally consisted of and understood with three components: input, internal process, and output although the term 'internal process' is varied among researchers. The three metabolic components are key elements of urban metabolism discussed in majorities of studies. In this study, we explored how these components of metabolism are referred and which elements are included. The integrated result of metabolic components and their elements are illustrated in Table 4.1. The component 'input' in general refers to imported and locally extracted resources within a system boundary (see, e.g. Newman, 1999; Barles, 2009; Haberl, 2011; Decker et al., 2000). The 'internal process' can be understood as social and economical metabolic activities in an urban system. The urban activities as internal process can also be regarded as cycles of material flows theoretically, for

Table 4.1 The integrated result of metabolic components and their elements. For more details about the origin of these elements, see Appendix 6.

Input	Internal Process	Output
Local/domestic extraction (e.g., sun, wind, fossil fuels, minerals) Imports (e.g., imported fossil-fuels and direct electricity)	(Energy or Material) Assimilation (conversion) Storage/accumulation Distribution Consumption Waste treatment	Wastes (e.g., soild waste, liquid waste, waste landfilled) Emissions (e.g., GHG) Residues (e.g., residual heat) Exports

example, resource conversion, storage, distribution, consumption, and treatment (see e.g. Zhang and Yang, 2007; Baccini and Brunner, 1991; Barles, 2009; Ngo and Pataki, 2009). An 'output' component includes metabolites, such as wastes, GHG emissions, residues, and exports to outside a system boundary (see, e.g. Newman, 1999; Barles, 2009; Decker et al, 2000; Haberl, 2011; Venkatesh and Brattebø, 2011).

4.1.5 Urban metabolism concepts and strategies

The idea of 'the city as an ecosystem' has associated with not only descriptive but also prescriptive theories of sustainable urban development with concepts and approaches studied from natural ecosystems (Girardet, 2008; Newman and Jennings, 2008). Therefore, concepts and its implications studied from natural ecosystems in urban metabolism studies are identified in this part of the report. Researchers from the tradition of industrial ecology identified several ecological concepts, providing the basis of this part (see, e.g. Korhonen, 2001, 2004; Korhonen and Snakin, 2005; Ayres and Ayres, 1996; Jelinski et al., 1992).

Roundput & Throughput

Material and energy flows are the basic principle of the ecosystem that all

Figure 4.5a Left: concept of roundput: cyclic- and cascading flows. Right: throughput.

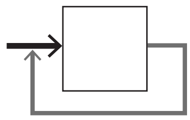


Figure 4.5b Strategy to recycle wastes as new input.

living organism depends on (Ayres and Simonis, 1994; Daly, 1996). Roundput and throughput (Figure 4.5a) are the types of material and energy flows that influence the resource utilization and waste generation in natural ecosystems (Korhonen and Snakin, 2005). Roundput refers to cyclical and cascading flows without wastes in food chains of natural ecosystems (Korhonen, 2001). In natural ecosystem, there exist producers (e.g. plants), consumers (e.g. animals), and decomposers (e.g. bacteria and fungi) (Husar, 1994; Geng and Cote, 2002). The roundput concept can also be seen in the carbon–oxygen cycle in nature, where oxygen as a waste produced by plants from carbon dioxide is considered as input to animals generating carbon dioxide as a waste (Ayres and Ayres, 1996). Contrary to this, the human ecosystems are illustrated as systems operated to a throughput direction (Korhonen, 2001). The term 'throughput' refers to energy-and material flows as resources that are used once, subsequently disposed as wastes (Jelinski et al., 1992; Ayres and Ayres, 1996). In this sense, the circular and linear models of urban metabolism can be understood with the concepts of roundput and throughput. Thus, when roundput concept is applied, human ecosystems can aim for a closed system with circular cycles that recycle materials and cascade energy (Ayres and Ayres, 1996). Theoretically, a successful application of the cyclical and cascading flows of roundput can contribute to sustainability of cities by reducing the input of energy and resources and the output of wastes and emissions as well as sustainable use of renewable resources.

The possible strategies for sustainable urban (energy) metabolism can be derived from the concepts of roundput and throughput as follows: recycling materials and wastes as input for another system components (Figure 4.5b). Also, cascading energy, for example, heat and electricity (see, e.g. Korhonen, 2004; Ayres and Ayres, 1996).

Diversity & Complexity

A system consists of several components (Zhang et al., 2009). Each system component has relations with the other interdependently (Korhonen, 2001). In the relations, diversity refers to the number of different actors involved (Figure 4.6a), for example species, and their interdependency in ecosystems (Korhonen, 2001, 2004). In natural ecosystems, biodiversity is considered essential for sustainable and resilient systems (Ring, 1997). Natural ecosystems adapt to a disturbance such as resource scarcity through diversity. For example, when a component escapes from a system, the system can still be performed with other components fulfilling their roles (Allenby and Cooper, 1994; Korhonen, 2001). Therefore, diversity in actors of

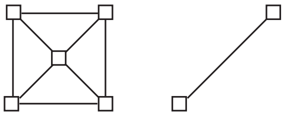


Figure 4.6a Left: high diversity of components, right: low diversity of components.

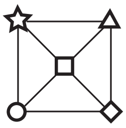


Figure 4.6b Strategy: increase diversity in input.

human ecosystems can also increase cooperation and interdependency, thus raising resilience and sustainability (Korhonen, 2001). For instance, the possibilities of waste recycling are more likely to increase when there are more co-operations between system components. In this sense, the concept of diversity has closely related to complexity concept. If ecosystems are more complex, they are less likely to be disrupted when a component suddenly departs from the system (Ulhoi and Madsen, 1998). Similarly, human ecosystems that have heavily relied on single or limited types of resource, for instance coal and oil, are less likely to be resilient and sustainable.

The possible strategies for sustainable urban (energy) metabolism can be derived from the concepts of diversity and complexity as follows: increasing diversity in system components and their interdependency through, for example, industrial symbiosis. Also, increasing diversity in types of input (Figure 4.6b) and output for resilient and sustainable metabolic systems (see, e.g. Korhonen, 2004).

Locality & Self-sufficiency

All natural ecosystems have to respect "the local natural limiting factors" (Korhonen, 2001). In nature, organisms tend to adapt to its surroundings by cooperating with other local organisms in a close proximity (Korhonen, 2001). Cities in human ecosystems have not

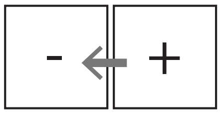


Figure 4.7a In self-sufficiency, resources are in close proximity.

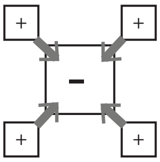


Figure 4.7b Strategy: local renewable energy assimilation

paid much attention to the concept of locality and local natural limiting factors, since they can easily import resources, for example, fossil fuels from outside the systems, increasing the dependency on foreign economies. Therefore, cities are regarded as unsustainable systems considering their dependence on imported material and energy as well as the exports of waste (Camagni et al., 1998). In this sense, the concept of locality has close relations with self-sufficiency concept (Figure 4.7a) in that self-sufficiency concept refers to reducing dependence from a wider hinterland for resources and waste disposal (Baccini 1997; Brunner 2007; Niza et al. 2009). Accordingly, locality in human ecosystems can be applied as the utilization of local energy and waste treatment within a system boundary considering possible harms on the environment, as well as co-operation between local components that are in close proximity with each other (Korhonen, 2001). Cities can be more sustainable in managing material and energy flows by designing cities that are energy efficient and less dependent on imported resources, (Holmes and Pincetl, 2012).

The possible strategies for sustainable urban (energy) metabolism can be derived from the concepts of locality and self-sufficiency as follows: increasing local renewable energy assimilations and distribution with local energy systems (Figure 4.7b), for example, district heating networks and smart grid. Recycling wastes locally as much as possible, then reusing wastes for food in a nature, respecting possible harms on the environment (see, e.g. Dobbelsteen, 2008). Increasing cooperation between local system components that are in close proximity with each other, for example, cascading of heat within a district.

Gradual change

Changes and processes in natural ecosystems usually take a long period of time at slow rates (Figure 4.8a), for instance in ecological succession (Ring, 1997). Contrastingly, cities and urban activities are characterized by fast rates. For example, raw materials and products are processed and manufactured relatively fast as the demands are rapidly increasing (Korhonen, 2001). In addition, nature depends on the renewable resources from the sun (Korhonen and Snakin, 2005). However, urban activities are based on the non-renewable resources such as fossil fuels, ignoring the 'time of nature' (Korhonen, 2001). When this gradual change concept applied, it can give insights to human ecosystems to promote gradual shift from fossil fuel to renewable resource-based system in the meanwhile exploit fossil fuels in a limited way (Salonen, 2010). Moreover, gradual changes can happen when materials and energy goes through the metabolic

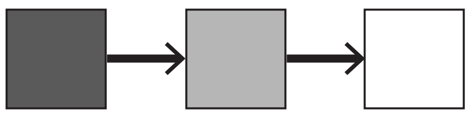


Figure 4.8a Changes in natural- as well as human ecosystems take a long period of time.

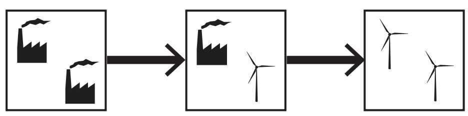


Figure 4.8b Strategy: changing the energy supply gradually in renewable energy.

cycle gradually by delaying the speed to provide more time to be utilized, for instance heat storage and cascading (Rovers, 2009).

The possible strategies for sustainable urban (energy) metabolism can be derived from the concepts of gradual change as follows: increasing the metabolic speed of energy utilizations through, for example, heat cascading and energy storage. Decreasing the reliance of fossil fuel gradually by increasing the use of renewable energy step by step is another example (Figure 4.8b).

4.2. Energy-conscious concepts & strategies

In this section, energy-conscious concepts from ecology and thermodynamics are identified with possible implications. For this part, several key literatures mostly from Sven Stremke (see, e.g. Strekme and Koh, 2010, 2011; Stremke et al., 2011, 2012) are used to form the main body of writings. Also, numerous energy-conscious strategies derived from both academic articles and practical cases in the field of environmental design are studied to form the generic list of strategies with identified concepts and strategies from urban metabolism and sustainable energy landscapes researches.

4.2.1 Ecological concepts & strategies

Energy flow

Energy flow (Figure 4.9a) can be described as energy transfer between systems or system parts (Lindeman, 1942 in Stremke and Koh, 2010). The flow of energy, for instance solar radiation, forms the characteristics of trophic structure and material cycling in natural ecosystems (Odum, 1969). Since the assimilation of solar energy is limited by

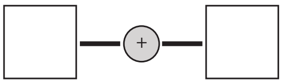


Figure 4.9a Energy flow: energy transfer between systems or system parts.

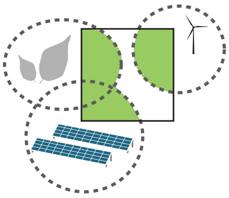


Figure 4.9b Strategy: identifying available areas for renewable energy assimilation.

the capacity to capture and store energy, it requires large areas to assimilate energy, causing pressure on land use (Stremke and Koh, 2010).

In this sense, possible energy-conscious strategies from the concept of energy flow can be made as follows: identifying available areas that have the potential for renewable energy assimilation: Figure 4.9b (Stremke and Koh, 2010).

Source and Sink

The 'source' area can be seen as an area whereas the rate of energy generation exceeds its use of energy. While in a sink area, the energy consumption exceeds the rate of assimilation (Odum 1997). Thus, source- sink relationships exist when a source area exports surplus energy to another area with an energy deficiency (Figure 4.10a).

In this sense, possible energy-conscious strategies from the concept of source and sink can be made as follows: increasing connectivity of corridors between already existing sources and sinks. Planning new energy sinks (e.g. algae plant and housing area) in the proximity of existing source areas: Figure 4.10b (e.g. industry with residual heat and geothermal heat) (Stremke and Koh, 2010; Stremke et al., 2011).

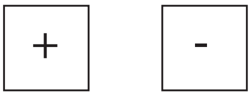


Figure 4.10a Source: energy generation exceeds consumption. Sink: energy consumption exceeds energy generation.

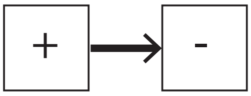


Figure 4.10b Strategy: increase connectivity between sources and sinks.

Diversity

The concept of diversity is essential to achieve a resilient system. Diversity in energy sources, carriers, and technologies can adapt to disturbances, for example periodic shortfalls of a source (Smil 2008). Also the diversity in a spatial aspect is important for resiliency of a system. For example, dispersal of wind turbine clusters across a region can cope with fluctuations in wind speed, ensuring stable energy generation (Laughton 2007).

In this sense, possible energy-conscious strategies from the concept of diversity can be made as follows: increasing diversity in potential energy sources, carriers, and technologies (Stremke and Koh, 2010) shown in Figure 4.11.

Differentiation of niches

Niche refers to an organism's living place in a system and how it responds to its food and competitors (Molles in Stremke, 2010). Ecosystems can be distinguished with types of niches in vertical stratification, horizontal zonation and temporal zonation (Koh, 1978). Ecosystems with highly differentiated niches are capable of sustaining more populations and species than other ecosystems with less differentiated niches (Pulliam and Johnson, 2002).

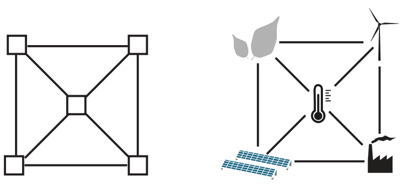


Figure 4.11 Left: diversity of components for a resilient system. Right: the strategy is to increase diversity in potential energy sources to overcome fluctuations in energy supply and demand.

In this sense, possible energy-conscious strategies from the concept of differentiation of niches can be made as follows: exploring potentials of an energy system for vertical stratification (e.g. Solar PV panels on flat roofs): see Figure 4.12a-b, horizontal zonation and temporal zonation (e.g. energy crop harvesting during wintertime in flood plain) (Stremke and Koh, 2011).

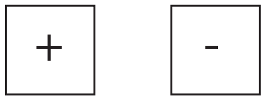


Figure 4.12a Horizontal stratification of land use: source and sink are separated and monofunctional.

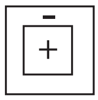


Figure 4.12b Vertical stratification of land use: source and sink are combined and multifunctional.

Primary production and Food chain

Primary production or photosynthesis refers to the process of fixating solar energy into biomass (Stremke and Koh, 2010). In nature, organisms can be classified with trophic levels: primary producers and consumers and secondary consumers (Figure 4.13a). Through trophic levels, energy is cascaded and each step in cascading has residual heat losses, decreasing the amount of energy through each successive level. However, energy cascading between organisms increases the overall energy utilisation in spite of conversion losses through trophic levels because resources are re-used effectively (Stremke and Koh, 2010). Therefore, in human ecosystems, cascading of residual heat can improve overall efficiency of the energy systems through waste recycling as another input (Stremke and Koh, 2010). In this sense, the concept of trophic levels in primary production concept can also be closely related to the concept of food chain. 'Food chain' refers to the relations between producers and consumers in the trophic levels of natural ecosystem (Stremke and Koh, 2011). Energy cascading can be described as "the use of residual energy in liquids or steam emanating from one process to provide heating, cooling or pressure for another" (Ehrenfeld and Gertler 1997).

Therefore, possible energy-conscious strategies from the concept of primary production and food chain can be made as follows: facilitating the residual energy cascading from high-grade functions (e.g. industry) to low-grade functions gradually (e.g. dwellings) (Stremke and Koh, 2010), see Figure 4.13b.

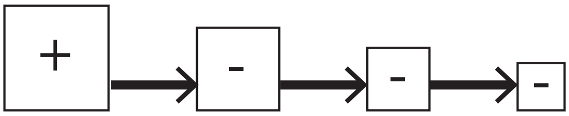


Figure 4.13a Primary- and secondary consumers use energy from primary production. The needed exergy varies per consumer/component.

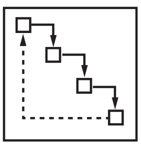


Figure 4.13b Strategy: cascade residual energy to match quality and demand.

Material cycling

Material cycling can be described as cyclic process of material and energy in natural ecosystems, which consists of material composition, consumption (material conversion) and decomposition. The transformations of energy through each process require energy for conversion (Stremke and Koh, 2010). In general,

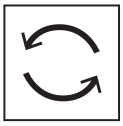


Figure 4.14a Material cycling within an ecosystem.

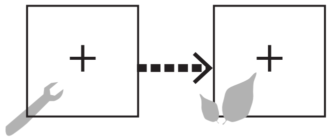


Figure 4.14b Strategy: natural processes as a substitute for energy-intensive processes to reduce energy consumption for material cycling.

the material cycling in ecosystems is considered a closed cycle. In today's cities, many of energy-consuming processes are technological process. Thus replacing the energy-intensive processes with natural processes has possibilities for reducing energy consumption (Todd et al., 2003).

In this sense, possible energy-conscious strategies from the concept of material cycling can be made as follows: replacing energy-intensive processes (e.g. wastewater treatment systems) with natural processes (e.g. water basins) (Stremke and Koh, 2010), see Figure 4.14a-b.

System size

System size means the spatial extent of a system (Stremke and Koh, 2010). In a natural ecosystem, the size of a system requires more energy to maintain that system when the size exceeds its energetic optimum (Odum and Odum 1976) (Figure 4.15). Environmental conditions such as the quantity and quality of available energy determine optimum system size (Odum, and Odum 1976). Since there exist different types of energy carriers in the human ecosystem, for instance heat and electricity, the energy carriers has different transportation costs and storage capacities, influencing respective system sizes (Stremke and Koh, 2011). Generally, renewable energy carriers such as biomass can serve in a small scale such as a neighbourhood or town (KNAW, 2007), while electricity grids can be transported to long distances (Stremke and Koh, 2011).

In this sense, possible energy-conscious strategies from the concept of system size can be made as follows: developing energy systems considering respective system sizes (Stremke and Koh, 2010).

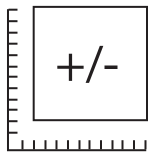


Figure 4.15 Strategy: system sizes should not exceed their energetic optimum.

Ecological succession

The concept of ecological succession refers to the gradual change in plant and animal communities (Figure 4.16a) in an area following a disturbance (Cooper cited in Molles, 2005). The disturbance of severe drought in a plant community can be comparable with a resource scarcity, for example, the depletion of fossil fuels that human ecosystems need to adapt (Stremke and Koh, 2010). Ecosystems develop in a way that the systems can increase resource utilization, leading to more complex and thus stable systems (Odum, 1992; Golley, Cited in Stremke, 2010). In this stable and mature ecosystem, materials and energy are used to increase interconnections between system components and the maintenance of structures (Newman, 1975).

In this sense, possible energy-conscious strategies from the concept of ecological succession can be made as follows: identifying possible renewable energy sources (Figure 4.16b) through, for instance, energy potential mapping (Dobbelsteen et al., 2007) (Stremke and Koh, 2010).

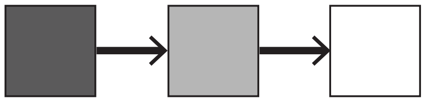


Figure 4.16a Ecological succession: similar to Figure 4.8a: a gradual change.

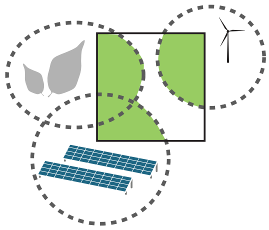


Figure 4.16b Strategy: identify areas for renewable energy assimilation, similar to Figure 4.9b.

Biorhythm and Storage

In a natural ecosystem, organisms adapt to less favourable periods to survive with the concept of biorhythm, for example, animal's hibernation and migration (Koh, 1978). Biorhythm can be described as the pattern of behavioral responses, in general, to periodic changes (Stremke and Koh, 2010). Biorhythm enables organisms to synchronize energy demand and supply (Molles, 2005). However, Human ecosystems have aperiodic lifestyle, which requires vast amount of energy to sustain it (Stremke and Koh, 2010). Thus, the challenge to achieve sustainable energy transitions is overcoming temporal fluctuations in energy demand and supply (Stremke and Koh, 2011). In this way, the concept of storage can be an answer for the challenge in that organisms exposed to periodic fluctuations in energy supply tend to store energy (Stremke and Koh, 2011). However, density and size of each energy carrier should be considered since they influence the capacity of energy storage in time and transport distance manner (e.g. how far) (Stremke and Koh, 2010).

In this sense, possible energy-conscious strategies from the concept of biorhythm and storage can be derived as follows: increasing energy storage (e.g. Storage of biogas produced from cattle manure locally or injected to gas grid system). Heat and cold storage temporarily underground (e.g. natural aquifers and abandoned mines) for later use. Sharing the same land surface for different functions (e.g. harvesting energy crops in the floodplains before flooding occurs during winter) (Stremke and Koh, 2010, 2011).

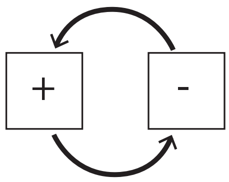


Figure 4.17a In biorhythm, fluctuations in energy supply- and demand occur.

Figure 4.18b Strategy: storage of energy can overcome fluctuations (Figure 4.17a). Storage can exist of e.g. thermal energy, biomass and biogas.

Mutual relationships and Symbiosis

The concept 'mutual relationships' refers to interactions of species that benefit each other (Boucher et al., 1982), for example, nutrient exchanges between fungi and some plants (Chapin, 1980 cited in Stremke and Koh, 2010). In natural ecosystems, mutual relationships are more likely to happen significantly when there exists resource scarcity in ecosystems (Odum 1992). And if different species sustain a mutual relationship over long periods of time, the relationship is considered 'symbiosis' (Stremke and Koh, 2011). In human ecosystems, if there is a resource scarcity, energy is more likely to be re-used and recycled (Stremke and Koh, 2010). In a mutual relationship or symbiosis, the more complex relationships involving a greater number of participants, the better possibilities to optimize their energy economy (Jorgenson, 2006).

In this sense, possible energy-conscious strategies from the concept of mutual relationships and symbiosis can be made as follows: identifying possible participants for mutual relationships (e.g. a greenhouse and a power plant): Figure 4.19. Identifying required infrastructure (e.g. roads, pipelines and waterways) for robust symbiotic networks between sinks and sources (Stremke and Koh, 2010, 2011).

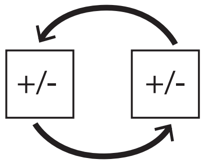


Figure 4.19 Strategy: identifying mutual relationships whereas two or more components benefit each other.

4.2.2 Thermodynamic concepts and strategies

Exergy and Entropy

All ecosystems are governed by the laws of thermodynamics. According to the first law of thermodynamics (FLT), energy cannot be created or destroyed, implying that 'the quantity of energy' is always conserved. While the second law of thermodynamics (SLT) describes that all spontaneous processes happen in a way that 'the energy quality' (e.g. exergy) is decreased and disorder (e.g. entropy) is increased (Wall and Gong, 2001) (Figure 4.20). In this sense, the concept of exergy (or available energy) refers to a measure of order, defined as the amount of work that can be obtainable when a stream of matter, heat or work comes into equilibrium with a reference or the surrounding environment (Dincer, 2000; Connely and Koshland, 1997). The entropy concept is described as a measure of a state of disorder: a randomized state of energy, which is unavailable for work directly (Dincer and Cengel, 2001; Wall and Gong, 2001). In optimizing energy

Table 4.2 Key literatures on energy-conscious concepts and strategies focused among 51 papers.

Energy-conscious spatial planning and design	- Stremke and Koh (2010, 2011) - Stremke et al. (2011) - Dobbelsteen et al. (2006) - Leduc (2008) -Tillie et al. (2009) -Roggema and Dobbelsteen (2009) -Leduc and Van Kann (2008, 2013) -Thayer (2008) -Thün and Velikov (2009) -Tischer (2013) -Oswalt et al (2005)
Energy-conscious urban planning	-Sadownik and Jaccard (2001) -Heba Allah E.E. Khalil, -Louis et al. (2007) -Sam C.M. Hui (2001) -Lehmann (2011) -Schmidt et al. (2012) -Ko (2013) -Leduc et al., (2009) -Leduc (2011) -Frenchman and Zegras, 2013)
Energy-conscious urban design	-Taylor, B. and Guthrie, P. (2008) -Barreiro et al. (2009) -Chance (2009) -Hagan (2013)
Energy-conscious Building design	-Robert Lowe (2007) -Sam C.M. Hui (2001)
Energy master plan of major cities (grey literature)	-City Instruments-the energy master plan of Zurich (2008) -City of Sydney decentralised energy master plan 2030 (2013) -City of Lafayette Energy Sustainability Master Plan (2009) -Report 2013 Netherlands energy scenario

systems with exergy perspective, several aspects that have a great influence on exergy should be considered importantly: the energy source, sink, the system environment, the energy sink, the energy infrastructure, and periodicity (Stremke et al, 2011). For example, hot water (i.e. the source) has more exergy during the winter (i.e. the system environment), and thus seasonal storage can increase exergy (i.e. periodicity). Also, a district-heating network (i.e. the energy infrastructure) near a source of hot water has more exergy (Stremke et al., 2011).

Energy-conscious strategies from second-law thinking

Second-law thinking is helpful in increasing exergy or improving energy system efficiency in the human built environment (Stremke et al., 2011). In order to minimize the loss of energy availability in human ecosystem due to the increase of entropy in any natural processes, the concept of exergy need to be considered and exergy should be preserved as much as possible (Stremke et al., 2011). In this context, the idea of exergy has been applied and developed in several disciplines, for example, engineering thermodynamics, industrial ecology, and Low-Ex approach in architecture and spatial planning. Stremke et al. derived five energy-conscious strategies for planning and design of the built environment from exergy-applied disciplines as follows (Stremke et al., 2011):

- increase exergy efficiency (e.g., heat recovery systems)
- decrease exergy demand (e.g., building orientation and passive house)
- increase use of residual exergy (e.g., residual heat for room heating)
- match quality levels of supply and demand (e.g., cascade)
- increase assimilation of renewable exergy (e.g., geothermal heat)

4.2.3 Energy-conscious strategies in environmental design

A transition to sustainable energy systems is concerned with various spatial-related disciplines. Energy-related topic and projects have become more and more important in the fields of environmental design such as urban planning, architecture, and landscape architecture with the clear correlation of renewable energy with space and landscape (Sijmons et al., 2008; Koh, 2005). Various energy-conscious strategies are identified through literature review in environmental design fields. Among numerous strategies identified through literature review, energy-conscious strategies with spatial implications are only focused considering the aim of this study. In this thesis, environmental design refers to the disciplines related to the spatial planning and design of the built environment, such as urban planning, urban design, spatial planning, architecture, and landscape architecture.

Nowadays, with the increasing concerns for climate change and renewable energy transitions, considerable researches with regards to renewable energy-conscious planning and design have been made in spatial-related disciplines. Key literatures that focused among 51 scholarly articles and practical papers such as cities' energy plan projects can be found in Table 4.2.

To list some examples, several studies on CO_2 neutral urban planning and spatial changes in terms of renewable energy transitions were researched (Tillie et al, 2009; Roggema and Dobbelsteen, 2009). Thun and Velikov have studied energy-conscious urban planning and architecture within the post-metropolitan condition of polycentric urban agglomerations in their research 'Infra eco logi urbanism' (Thun & Velikov 2013). Frenchman and Zegras researched the relationship between urban form and renewable energy performance focused on neighborhood-scale (Frenchman & Zegras, 2013). Susannah Hagan studied park and urban design in terms of metabolic function of energy (Hagan, 2013). Stefan Tischer researched structures of electric power supply and solar parks in Mediterranean areas (Tischer, 2013). Philipp Oswalt researched spatial changes in post-fossil fuel cities with relations to renewable energy transition (Oswalt et al, 2005). Sven Stremke explored design principles and a methodological framework of sustainable energy landscapes at regional scale (Stremke, 2010).

Based on the literature review on energy-conscious strategies, the results are integrated and suggested with three categories: urban planning, site and building design, and transport management according to the classifications in listing energy-conscious strategies in Sadownik and Jaccard's paper (Sadownik and Jaccard's, 2001):

Urban planning
- Facilitating high-density development that prevents diffusion of functions in the city (e.g., urban sprawling) to reduce transport distance of energy and people (less energy loss in energy transportation and less energy required for traveling);
- Facilitating high-density development that prevents diffusion of functions in the city (e.g., urban sprawling) to reduce transport distance of energy and people (less energy loss in energy transportation and less energy required for traveling);
- Allocating decentralized business functions in proximity to public services and residential areas to reduce travel distances (e.g., integrating decentralized business functions with residential areas: combine work and living);
- Establishing mixed-land use that allows heat exchange (e.g., dwelling and supermarket in the same building or close to each other);
- Promoting more green open spaces which affect temperature and humidity (e.g., to reduce energy consumption for heating and cooling);
- Developing urban areas with a mixture of high and low buildings for better ventilation conditions.

Transport management
- Promoting public transportation by optimum connections through various modes of transportation;
- Facilitating bicycle and walking (e.g., well-designed bicycle track systems and parking areas near transit stops);
- Ensuring the smooth movement of traffic on main roads (e.g., road layout).

Site and building design
- Orientation of buildings to make optimal use of solar energy influx;
- Use of trees near building to block summer sun and allow winter sun;
- Encouraging energy efficient building (e.g., thermal insulation of walls, triple-glazed windows);
- Designing with microclimate that influences heating, cooling and lighting demands (e.g., green space, cool surface of water, differential building heights and wider streets);
- Use of renewable energy technologies in building (e.g., solar PV, solar thermal, micro wind turbine) with geothermal heat pumps and micro CHP;
- Use of building envelop materials with high albedo.

4.3. Conclusions

We have discussed 7 urban metabolism concepts and their strategies, which are based on properties of natural ecosystem, and 15 concepts and applied strategies of ecology and thermodynamics from ongoing researches on sustainable energy landscapes, as well as 15 strategies derived from energy-conscious academic articles and practices in environmental design fields. They provide insights on how to achieve sustainable urban energy systems with the optimized-linear metabolism models (based on the previously circular models) and accounting methods derived from identified concepts and strategies. Therefore, we suggest prescriptive strategies for sustainable urban(energy) metabolism under the 3 metabolic components (Table 4.3). They are based on urban metabolism concepts and strategies identified including roundput & throughput, locality & self-sufficiency, diversity & complexity, and gradual change. In discussing the metabolic component of input, minimizing the volume of input is important to be resource-effective (instead of resource-consuming) and sustainable systems in that (1) a human ecosystem need to respect natural limits of resources (e.g. depletion of resources) and (2) to be self-sufficient with only renewable energy sources considering the limited rate of assimilation (also causing land-use pressure), energy demand of a system should be reduced with reduced input volume. This can be achieved by, for example, energy-efficient technologies and building. However, one should consider not only the volume of input (e.g. reducing input) but also the type of input, which are environmentally sustainable (e.g. renewable sources instead of fossil fuels) considering the sustainability goal of urban metabolism. In terms of the internal process component, interdependency and cooperation among system components should be increased for efficient use of energy and less energy loss in conversion. System components or urban activities can be described as material cycling or steps in trophic levels, such as energy assimilation, storage, transport, consumption and waste treatment or decomposition. Here, the quality of energy from exergy concept is essential because, for example, residual energy from a system component can be useful in another component. Thus, this can be achieved by symbiotic relationships, cascading and heat exchange among system components. Also, as discussed in the gradual concept, delaying the speed of metabolic cycle can provide more time to be utilized, for instance heat storage and cascading (Rovers, 2009). Lastly, about the output issue, there are two types of output: output with and without potentials that can be used as energy in another consumptive process in a system. However, exergy should be considered importantly in discussing the output. This is because wastes (e.g. residual energy) as output still has the same energy to input but only the quality of energy (exergy) are decreased compared to the earlier phase (e.g. input). In this way, the two types of output mentioned above can be regarded output with and without enough exergy to be used directly. Thus, output that has enough exergy for use in other urban activities (e.g. residual heat) should be recycled or reused for consumptive and productive uses. Then, the type of output without enough exergy should be used for food (e.g. using liquid waste for manure in a farm and CO_2 for aquatic farm) as much as possible.

Additionally, most of metabolism models tend to ignore the inner components, their activities and relations

Table 4.3 Strategies for sustainable urban (energy) metabolism.

Input	• (Volume of input) Minimizing the volume of input by reducing energy demand • (Type of input) Using renewable sources for input instead of fossil fuels
Internal process	• Increasing interconnections among system components • Reducing the speed of internal process to exploit exergy as much as possible
Outputs	• (Volume of output) Minimizing the volume of output by recycling wastes (and residues) with energy potentials for internal process (for consumptive and productive uses) • Using wastes without energy potentials for food as much as possible (while respecting natural limits)

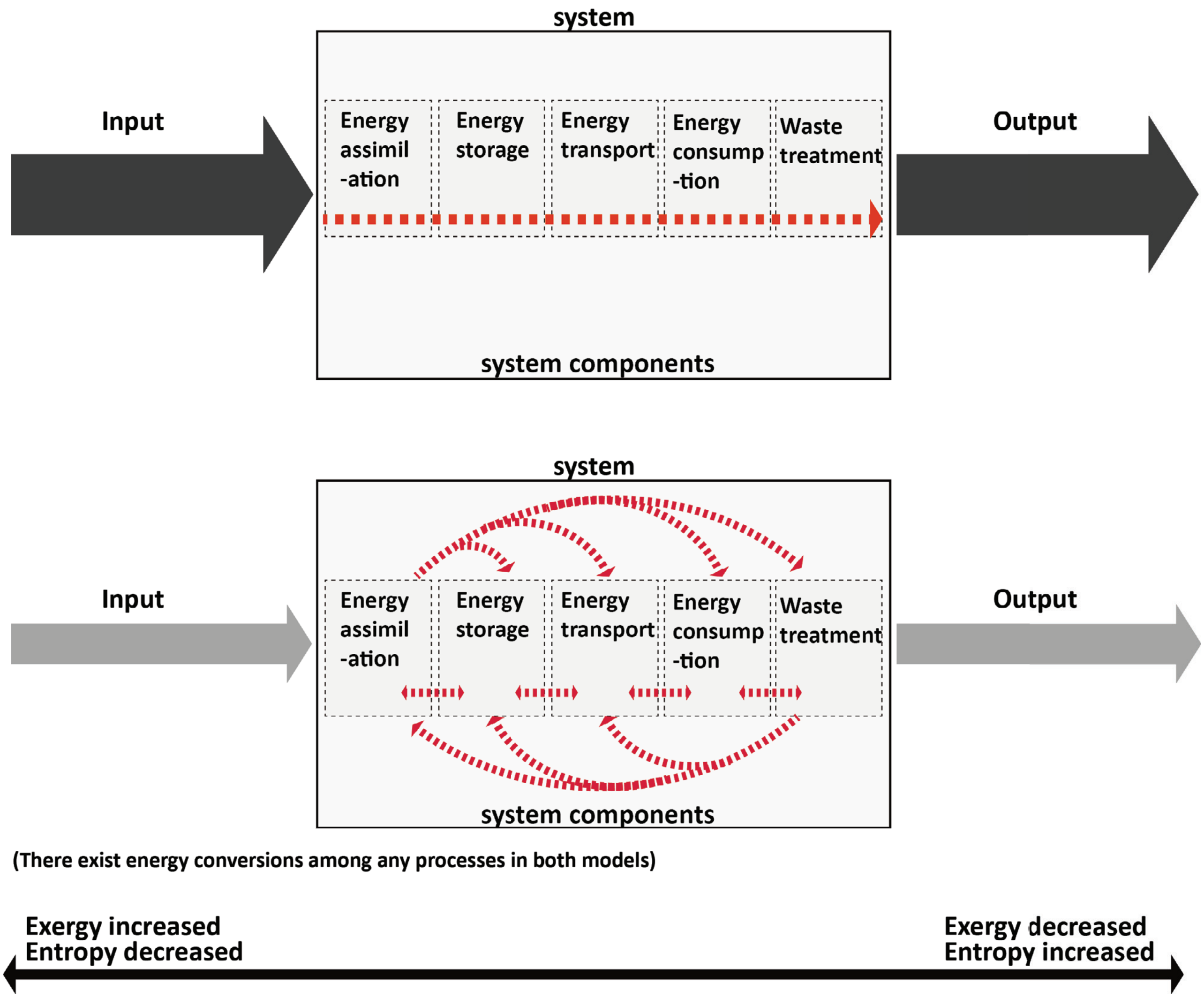


Figure 4.20 Suggested linear and optimized-linear metabolism models, describing inner system components and their linear- and cyclical process.

within a system. For example, the model of network process, only illustrating material and energy transformation in a system (see, e.g. Zhang et al, 2013). Therefore, we would like to suggest an adjusted model of urban metabolism focusing more on inner metabolic process based on previous network models (Figure 4.20).

However, we still lack generally applicable strategies, which are integrated through synthesis and translation of studied knowledge from various approaches and disciplines in this thesis. Thus, we would like to suggest a generic list of energy-conscious strategies with the number of times mentioned during the literature review for each strategy. More importantly, the strategies are framed with urban metabolism concept by showing the relevance of each strategy to 3 components of urban metabolism: input, internal process, and output, and these components should be understood with above proposed strategies for sustainable urban (energy) metabolism. Therefore, a strategy in the list with a close relevance to input column, for example, it is illustrated with one to three marks in the list (Table 4.4). In this way, if a strategy has three marks in input column, that strategy has more important value in the input than other metabolic components.

Table 4.4 A generic list of integrated energy-conscious strategies with relevance to 3 metabolic components Note: (1) each mark of strategies showing relevance to metabolic components should be read horizontally, not vertically in a sense that the relevances are to be compared. (2) For each strategy, the number of times mentioned during the literature review is stated.
Key: ***=focal components, **=relevant , *=less relevant

	Input	Internal process	output
Urban planning			
-Facilitating high-density development that prevents diffusion of functions in the city (e.g. urban sprawling) to reduce transport distance of energy and people (mentioned 3 times)	**	***	*
- Allocating decentralized business functions in proximity to public services and residential areas to reduce travel distances (e.g. Integrating decentralized business functions with residential areas) (mentioned 3 times)	**	***	*
- Establishing mixed-land use that allows heat exchange (e.g. dwelling and supermarket in the same building) (mentioned 2 times)	**	***	**
- Promoting more green open spaces which affect temperature and humidity (mentioned 4 times)	**	*	*
- Developing urban areas with a mixture of high and low buildings for better ventilation conditions (mentioned 2 times)	**	*	*
Transportation management			
- Promoting public transportation through optimum connections among various modes of transportation (mentioned 3 times)	**	*	***
- Facilitating bicycle and walking through, for example, well-designed bicycle track systems and parking areas near transit stops (mentioned 3 times)	**	*	**
- Ensuring the smooth movement of traffic on main roads by, for example, improving road layout (mentioned 1 time)	**	*	**
Site and building design			
- Orientation of buildings to make optimal use of energy influx (mentioned 5 times)	***	*	*
- Use of trees near buildings to block summer sun and allow winter sun (mentioned 4 times)	**	*	*
- Encouraging energy efficient building (e.g., thermal insulation of walls, triple-glazed windows) (mentioned 6 times)	***	*	*
- Designing micro-climate that influence heating, cooling and lighting demands (e.g., cool surface of water, differential building heights and wider streets) (mentioned 4 times)	**	*	*
- Use of renewable energy technologies in building (e.g. micro wind turbine and solar PV) (mentioned 8 times)	***	*	**
Renewable energy utilization* *Energy utilization refers to the assimilation, conversion, storage, transport and use of energy			

(1) Energy assimilation and storage - Increasing renewable energy assimilation at different scales (e.g. large offshore wind farms and concentrated solar power plants) (mentioned 7 times)	***	*	**
- Identifying potential areas for renewable energy assimilation from diverse sources (mentioned 7 times)	***	*	**
- Increasing a diversity of renewable energy sources, carriers, technologies (mentioned 3 times)	*	***	*
- Developing interconnected energy systems considering respective system sizes (mentioned 3 times)	*	***	*
- Distributing different renewable energy assimilation clusters across different areas in a region (mentioned 2 times)	**	***	*
- Sharing the same land surface for different functions for renewable energy assimilation (e.g. energy crop harvesting in flood plain during wintertime) (mentioned 1 time)	**	***	*
- Employing 'stand alone' systems in low-density housing areas which are separate from public networks (e.g. heat/cold pumps and solar PV in a remote area) (mentioned 2 time)	**	**	*
- Increasing heat and cold storage underground (e.g. seasonal storage in aquifers or old mines) (mentioned 2 times)	**	***	*
- Increasing energy storage through resource accumulation (e.g. storage of soild and liquid biomass) (mentioned 7 times)	**	***	*
(2) Flow of energy - Minimizing energy demand by decreasing energy consumption (e.g. natural ventilations) (mentioned 8 times)	***	**	*
- Identifying existing energy sources-sinks and increase the connectivity (e.g. power plants and greenhouses) (mentioned 2 times)	*	***	**
- Allocating, if necessary, new energy sinks in proximity to sources (mentioned 2 times)	*	***	**
- Clustering and networking areas with the same energy quality demands (mentioned 4 times)	*	***	**
- Matching energy quality of sources and sinks (e.g., geothermal energy for room heating) (mentioned 3 times)	*	***	***
- Identifying and facilitating symbiotic relationships with relevant infrastructure (e.g. cattle farmer and energy plants) (mentioned 1 time)	***	***	***
- Cascading residual energy from high-grade functions through a series of lower-grade functions (e.g. from industry to dwellings and greenhouses)	***	***	***

(mentioned 4 times)			
- Recycling waste resources from consumptive process for another one (e.g. converting waste heat from water purification plants into different forms of energy in CHP) (mentioned 6 times)	***	***	***
- Reusing waste outputs for food production to minimize waste production (e.g. reusing by-products of biomass as a fertilizer) (mentioned 3 times)	*	**	***
- Creating infrastructure near high potential areas for renewable energy (e.g. district heating near geothermal) (mentioned 2 times)	*	***	**
- Replacing energy-intensive processes with natural ones (e.g. replacing parts of water treatment systems with wetlands) (mentioned 1 time)	***	*	*
- Facilitating the use of energy-efficient technologies to reduce transportation and conversion loss (e.g. Cogeneration and trigeneration) (mentioned 3 times)	*	***	***
(3) Energy distribution - Clustering diverse renewable energy sources with local energy systems (e.g. Decentralized energy system of smart/micro grid, electric network, district heating network, open heat-cold storage, CHP and renewable energy assimilation) (mentioned 7 times)	**	***	***

5. CASE STUDY

The case study commences with an introduction of Amsterdam and its land-use. Subsequently Amsterdam's energy system is analysed, and finally an analysis of the city's energy consumption and renewable energy potentials are shown. This case study helps to answer sub research question 2 and provides findings about Amsterdam's energy utility, which are fundamental input for Chapter 6 'Energy-conscious strategies for Amsterdam.'

5.1 Land-use inventory

5.1.1 Cultivating wet land

Many centuries ago Amsterdam was not a place suitable to live. A swampy landscape with high water levels would seem impossible to inhabit. But after 1000 A.D. swampy areas were drained by people in small communities who dug ditches, connected to natural peat streams such as the Amstel (Berendsen, 2008). Animal- and human work power were the first forms of energy that were performing work -cultivating land- in the western peat region of the Netherlands.

Because water was carried away from the peat soils, settling of peat occurred constituting the danger of flooding in low-lying areas. It was learned that the water table should be kept high enough to prevent land from lowering. Some areas around Amsterdam became dangerously low, whereas since 1500 A.D. areas had to be drained again. Construction of floodgates and water drainage by windmills had to control the water table. The wind mills pumping water away marked the first renewable energy systems in medieval times. Due

Table 5.1 Percentages of land-use in Municipality Amsterdam. Source: Amsterdam in Cijfers (2012)

Land-use in Municipality Amsterdam (2012)
Source: DRO/Statistiek Bodemgebruik

Land-use	Surface (ha)	Surface (km2)	%
Traffic terrain			
Railway terrain	396,86	3,97	1,8
Road traffic terrain	1.202,57	12,03	5,5
Airport	0,64	0,01	0,0
Total	1.600,07	16,00	7,3
Built terrain			
Residential terrain	4.529,08	45,29	20,6
Terrain for retail, shops and hotel & catering	325,32	3,25	1,5
Terrain for public supplies	205,41	2,05	0,9
Terrain for social-cultural supplies	529,06	5,29	2,4
Company terrain	2.322,90	23,23	10,6
Total	7.911,77	79,12	36,1
Semi-built terrain			
Wreck storage place	7,30	0,07	0,0
Cemetery	124,11	1,24	0,6
Building site	1.254,64	12,55	5,7
Semi-paved additional terrain	48,67	0,49	0,2
Total	1.434,72	14,35	6,5
Recreation terrain			
Park and public garden	1.375,01	13,75	6,3
Sport terrain	680,87	6,81	3,1
Allotment garden	341,37	3,41	1,6
Day recreation terrain	62,76	0,63	0,3
Recreation residence terrain	19,10	0,19	0,1
Total	2.479,11	24,79	11,3
Agricultural terrain			
Terrain for greenhouses	25,22	0,25	0,1
Additional agricultural terrain	2.525,88	25,26	11,5
Total	2.551,10	25,51	11,6
Forest and natural terrain			
Forest	349,18	3,49	1,6
Open dry natural terrain	73,24	0,73	0,3
Open wet natural terrain	81,56	0,82	0,4
Total	503,98	5,04	2,3
Water			
Ijsselmeer/Markermeer	2.236,88	22,37	10,2
Recreational inland water	350,05	3,50	1,6
Additional inland water wider than 6 m	2.865,41	28,65	13,1
Total	5.452,34	54,52	24,9
Total	21.933,09	219,33	100

Figure 5.1 Amsterdam in early 1600. Amsterdam had a strategic position closeby the North Sea, making the port an outstanding location for trade. Source: freeamsterdam.nl

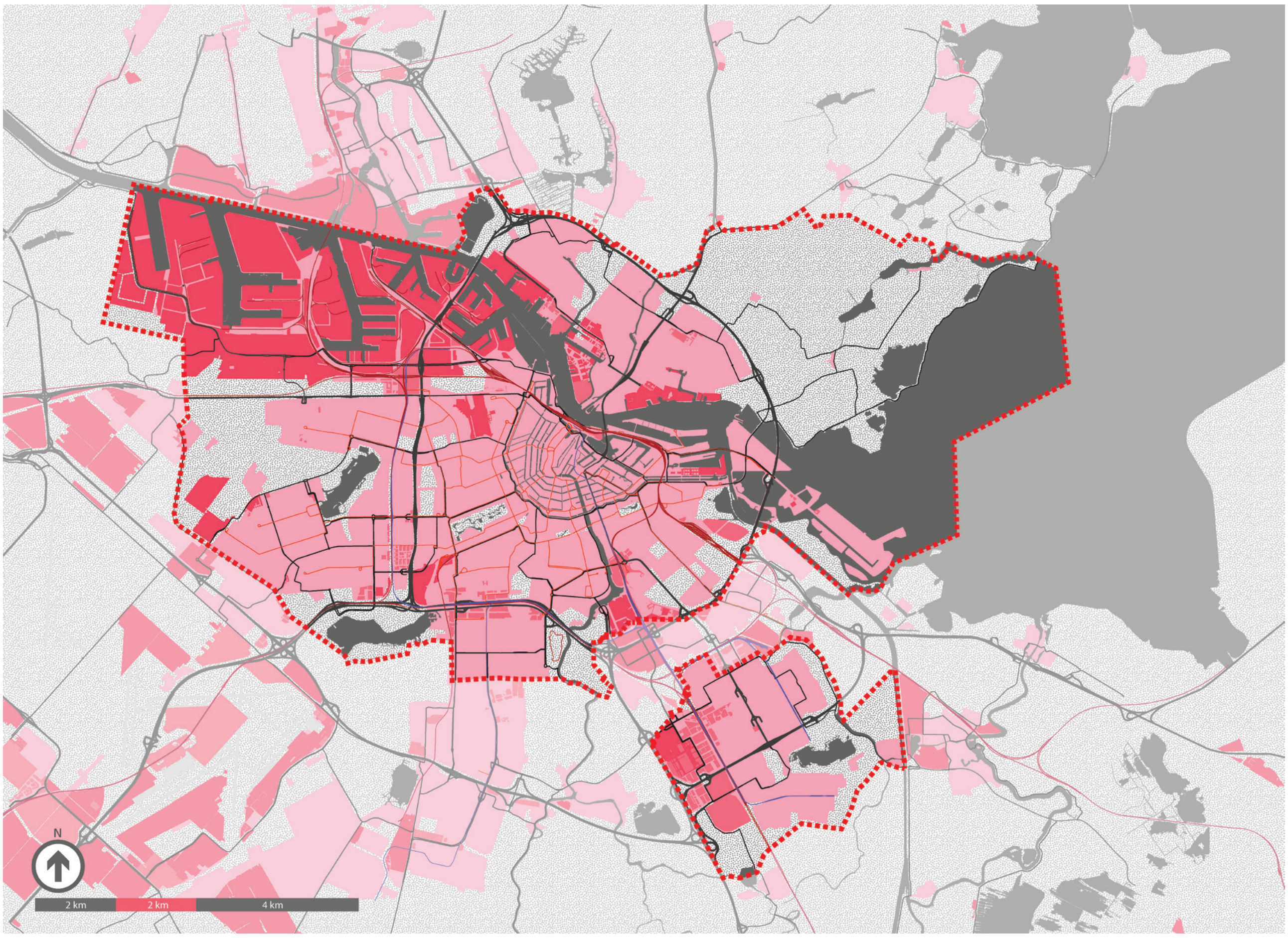


Figure 5.2 Land-use of Amsterdam: a simplified display reducing complexity. Edited from ArcGIS (2014).

to developing technology water was being drained by steam-, diesel-, and electrical pumping stations since 1850 A.D (Berendsen, 2008).

5.1.2 A blooming city

In the 15th century Amsterdam became the most important trade city of the Netherlands. The recognisable ring-shaped canals were built at the expansion of the city. Houses were built on wooden poles, resting on the sand layer beneath the low load bearing peat soil. Amsterdam's soil still contains a dense forest of wooden and concrete poles, all to carry its buildings on top of them (kennislink.nl, 2011).

In the Golden Age (17th century) the Netherlands experienced booming business largely caused by successful international trade, with the port as a central point (Figure 5.1). Simultaneously Amsterdam needed another expansion of the city due to economic development with increasing population. Warehouses and merchant houses became characteristic for the old city centre. The Industrial Revolution constituted intensified trade, again increasing population and new industry.

5.1.3 Public lighting: from gas to electricity

Before electricity utility emerged in Dutch cities, gas was a common energy carrier in Amsterdam. Since 1885 two gas factories distilled gas from coals (Gemeente Amsterdam, 2009). For the most part this gas was used for gas lanterns illuminating Amsterdam's streets. Since 1904 electric arc lamps began to substitute the gas lanterns: eventually in 1923 all gas lanterns were electricifed (ibid). Electricity was deliverd by power plants that emerged in the Netherlands in 1886 (IS Geschiedenis, 2012).

5.1.4 Current situation

Nowadays Amsterdam has a population of almost 811.000 (CBS, 12 Dec. 2014). The total surface of the municipality is 219,33 km2 of which 164,89 km2 is land (Bureau Onderzoek en Statistiek, 2013). Agricultural land lies for the most part in the north-east of the municipality, whereas the amount of land in this region is the highest: 41,79 km2 (ibid). Residential areas form the highest percentage of land-use: 20,6% with 45,3 km2 (Table 5.1). The Port of Amsterdam is ranked as the 4th port of Europe with large transhipments of e.g. cacao, coal and oil products (Port of Amsterdam, 2013). Industrial areas are largely concentrated around the port and in district Zuidoost (Figure 5.2). Tourism is highly concentrated in the city centre and surrounding areas, offering various attractive functions such as museums, shops, restaurants and boating on canals. Because Amsterdam has a high concentration of economic activities, highways in and around the city contain a high intensity of car traffic. The electric railway infrastructure exists of trains, subways and trams whereas the characteristic tram network offers wide connectivity throughout the whole city.

5.2 Energy in Amsterdam

In paragraph 5.2.1 the existing infrastructure relevant for energy is analysed. Sources, storage and connections of energy are showed in this analysis. Subsequently the energy flow analysis of Amsterdam is showed in paragraph 5.2.2. This is a quantitative analysis that shows what goes in and out the municipality in terms of energy.

5.2.1 Energy infrastructure analysis

Looking at centralized energy deliverance in the form of electricity, gas and heating, two large power plants are present: Hemweg and Diemen (Figure 5.3). Both power plants are owned by Nuon, a utility company that provides electricity, gas and district heating in the Netherlands, Belgium and the United Kingdom. Hemweg exists of three units: 7, 8 and 9 (Figure 5.6). Hemweg 8 from 1994 runs on coals whereas Hemweg 9 from 2012 runs on gas and internally produced steam (Nuon, 2013). Combustion of natural gas emits less CO_2 than combustion of other fossil fuels such as coal (Vattenfall AB, 2011). Hemweg 9 is therefore relatively 'cleaner' compared to Hemweg 8. Hemweg 7 from 1979 also runned on gas and steam but the plant closed in 2013 due to its age and therefore low efficiency considering contemporary technology. The Diemen power plant exists of two units: 33 from 1995 and 34 from 2013. Just like Hemweg 9, Diemen 33 and 34 run on natural gas and steam. District heating is supplied by the Diemen power plant (den Boogert et al., 2014, p.42-43), which makes Diemen a cogeneration plant (see Figure 5.4). A power plant is a cogeneration plant when

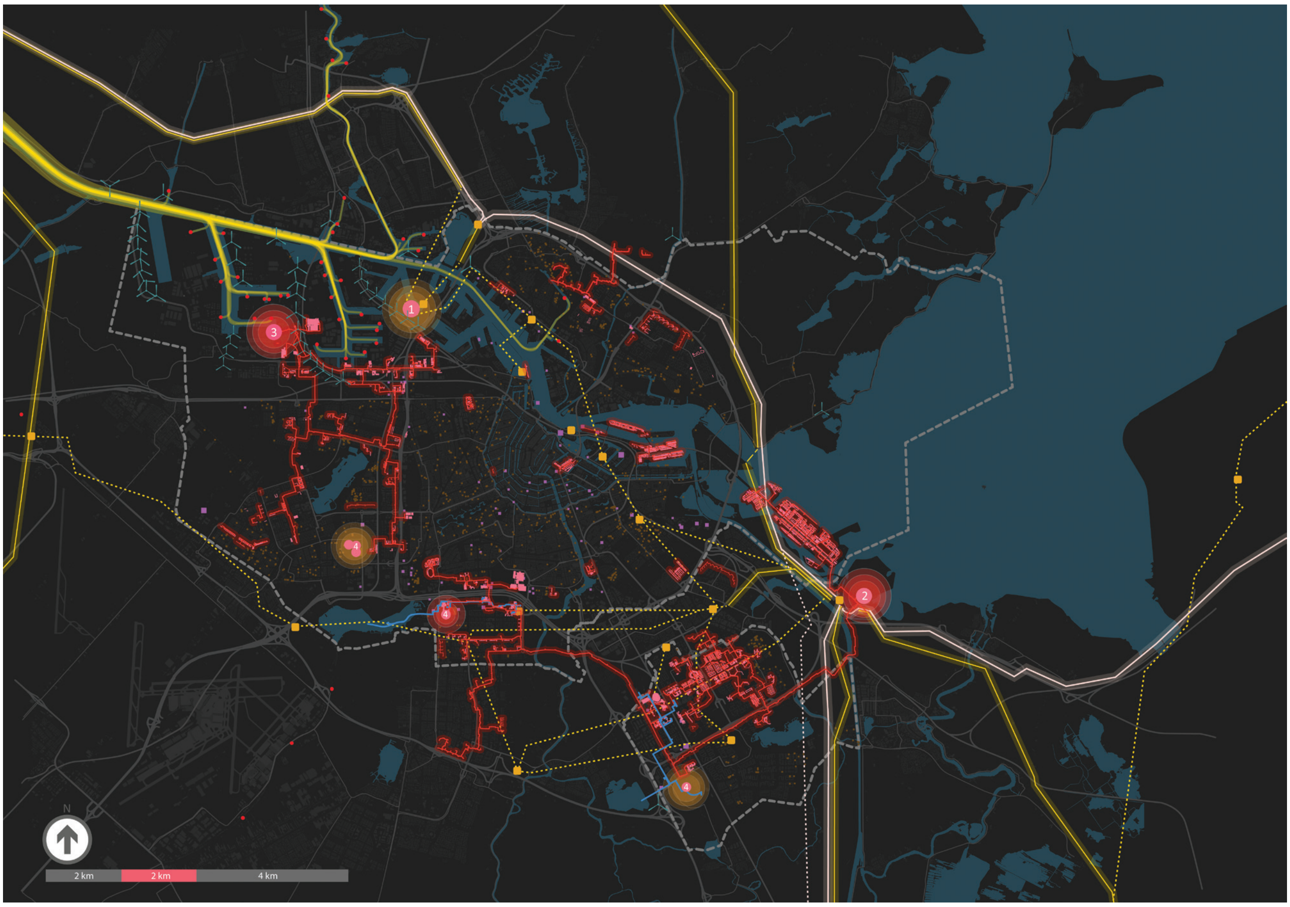
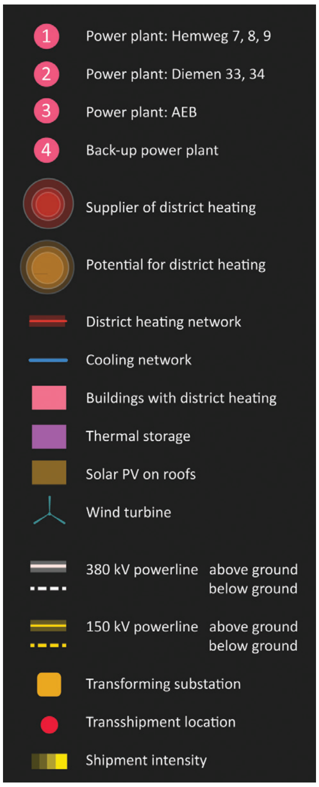


Figure 5.3 Energy infrastructure of Amsterdam. Edited from ArcGIS (2014), TenneT (2011) and Energy Atlas (2014).



residual heat is utilized. Residual heat from energy generation processes is directly extracted and added to the district heating network. Buildings (e.g. homes, offices and industry buildings) connected to the heating network are able to utilize this heat for example for space heating and water heating. The Hemweg powerplants are not connected to the heating network, although they have a potential as large supplier of district heating.

The shipment intensity indicates where goods are transhipped in the port of Amsterdam. Power plant Hemweg 8 combusts coal each year, therefore Hemweg 8 is located in proximity to transhipment locations for coal. Coal is subsequently being transferred on conveyor belts to the power plant.

Two voltages of power lines are present: 380 kV and 150 kV which are owned and maintained by TenneT. TenneT is an electricity transporter company in Europe with approximately 20.000 km of high voltage power lines (TenneT, 2011). Power lines in Amsterdam are directly connected to power plants via transforming substations. These substations regulate the right amount of power of electricity to the grid.

AEB is a company located in the port and converts domestic waste and biomass into energy in the form of electricity and heat (see Figure 5.5 and 5.7). Waste is literally a resource for energy in this case. Although the high voltage power lines are not connected to AEB, the company does deliver electricity through smaller scale power lines. AEB is just like the Diemen power plant a supplier of district heating (den Boogert et al., 2014, p.42-43), and therefore like Diemen a cogeneration plant.

Especially in the West and South-East of Amsterdam the district heating network is extended. The heating network made of insulated pipes exists of 'feed and return' lines. The most common medium for heat transfer is hot water or steam. Not only the Hemweg power plant is an unused potential for district heating, but also small back-up power plants can be used as heat supplier. The cooling network is very limited compared with the heating network. With the cooling network cold water from lakes is extracted, subsequently the cold water can be used for cooling spaces and water. Limitations in the cooling network might be caused by less importance of cooling compared with the heating demand in the city. Direct heat and cold can be substitutes for electricity and gas, in a sense that electricity and gas are less needed for heating and cooling spaces and water.

Solar PV systems on roofs are just like thermal storage points scattered across the city. Over 9.200 solar PV systems are installed in Amsterdam, and over 200 thermal storage points (den Boogert et al., 2014, p.42-43). Considering the thermal storage points are not linked to the district heating- and cooling network they are probably connected to singular building or clusters of buildings in a decentralized way. Wind turbines can be found in several areas, most of them in the port (den Boogert et al., 2014, p.44-45). Nowadays electricity from wind of approximately 480 TJ/year can be delivered from wind turbines within the municipality boundary (Rijkswaterstaat, 2012). There are limited possibilities in extending the amount of wind turbines due to environmental policies. For example view, noise and casting shade have high influence in preventing wind turbines close to residential areas (IBA, 2012). Charging points for electric cars are not mapped but just like the thermal storage points scattered in the city as well. In November 2014 Amsterdam counted 1.006 park- and charging points, used by 3.748 motorists (Gemeente

Figure 5.4 Power plant Diemen 33 and 34. Diemen is a supplier of district heating. Source: www.pennenergy.com

Figure 5.5 Heat storage tanks of AEB. Text on the tanks says: "waste is warmth". Source: www.noord.amsterdam.nl

Figure 5.6 The power plants Hemweg supplies electricity by means of coals and natural gas. It's residual heat however is disposed into the air, while it has potential for district heating. Source: www.kecpro.com.

Figure 5.7 AEB located in the port of Amsterdam processes waste into electricity and district heating. Source: www.nieuwsbrief.amsterdam.nl

Amsterdam, 2014). The amount of park- and charging points is still developing with the aim to increase the electrified driven kilometres by cars.

5.2.2 Energy flow analysis

Amsterdam's current energy mix is largely based on fossil fuels (Rijkswaterstaat, 2012). These fossil fuels are imported and constitute dependency on external grounds. In order to assess how green and efficient Amsterdam is in terms of energy, but also how much energy the city needs, an energy balance of Amsterdam is established. The question is then: how much and what kind of energy is imported and locally generated, and where does this energy go to? The energy balance is represented by a Sankey diagram. Sankey diagrams are often used for representing (industrial) metabolism and can "identify inefficiencies and potentials when dealing with resources" (Schmidt, 2008, p.1). Next to the current energy balance, an interpretation of the prospective energy balance is showed. The prospective energy balance (Figure 5.9) suggests Amsterdam's improved energy metabolism in 2040.

Current energy balance

Amsterdam's current energy balance (Figure 5.8) showed in this chapter is based on quantitative data, gathered from Klimaatmonitor (Rijkswaterstaat, 2012), Nuon, Central Bureau of Statistics (CBS) and Port of Amsterdam. Figure 5.8 has smaller flows of oil and coil than in actual proportions, due to the limited report size. The actual proportions are viewed in Appendix 5. Datasheets as underlying information are showed in Appendix 2. The energy balance represents a yearly basis. In this case the year 2012 is taken because 2012 contained most information for the needed data. When specific numbers were not measured and/or published, calculated assumptions were made. All specific clarifications of data for Amsterdam's current energy balance are showed in the appendices. All numbers in the Sankey diagram are in Terajoule (TJ) in order to illustrate comparable energy flows with related proportions. Units in data used for electricity were directly able to be converted into TJ. However resources like natural gas, coal and oil products are converted into TJ with 'Caloric values' (CBS, n.d.), a list of various resources with a certain energetic value in Terajoule (see Appendix 1). The considered system boundary is Municipality Amsterdam. Anything going in- or outside this administrative boundary is considered as import or export. In this report it is still not sure if all generated electricity is also consumed in Amsterdam. Net manager Liander probably has more information about this issue. For a comparison between local energy generation and local energy consumption, it is assumed that locally generated energy is also consumed in Amsterdam whereas possible surplus of energy is exported. The consumption sectors are: household, industry, agriculture, transport and utility. Utility is considered as business-like buildings, this exists of for example not only companies, but also schools, health care and cultural buildings: basically anything that is not a dwelling or industrial building.

Amsterdam already has a variety of renewable energy sources generating energy locally. This amount however is relatively small compared to input of coal and natural gas for electricity- and gas supply through the grid. Amsterdam imported 17.820.000 tons of coal in 2012 (Port of Amsterdam, 2012). Each year 1.600.000 ton coal of that import is combusted in the power plant Hemweg

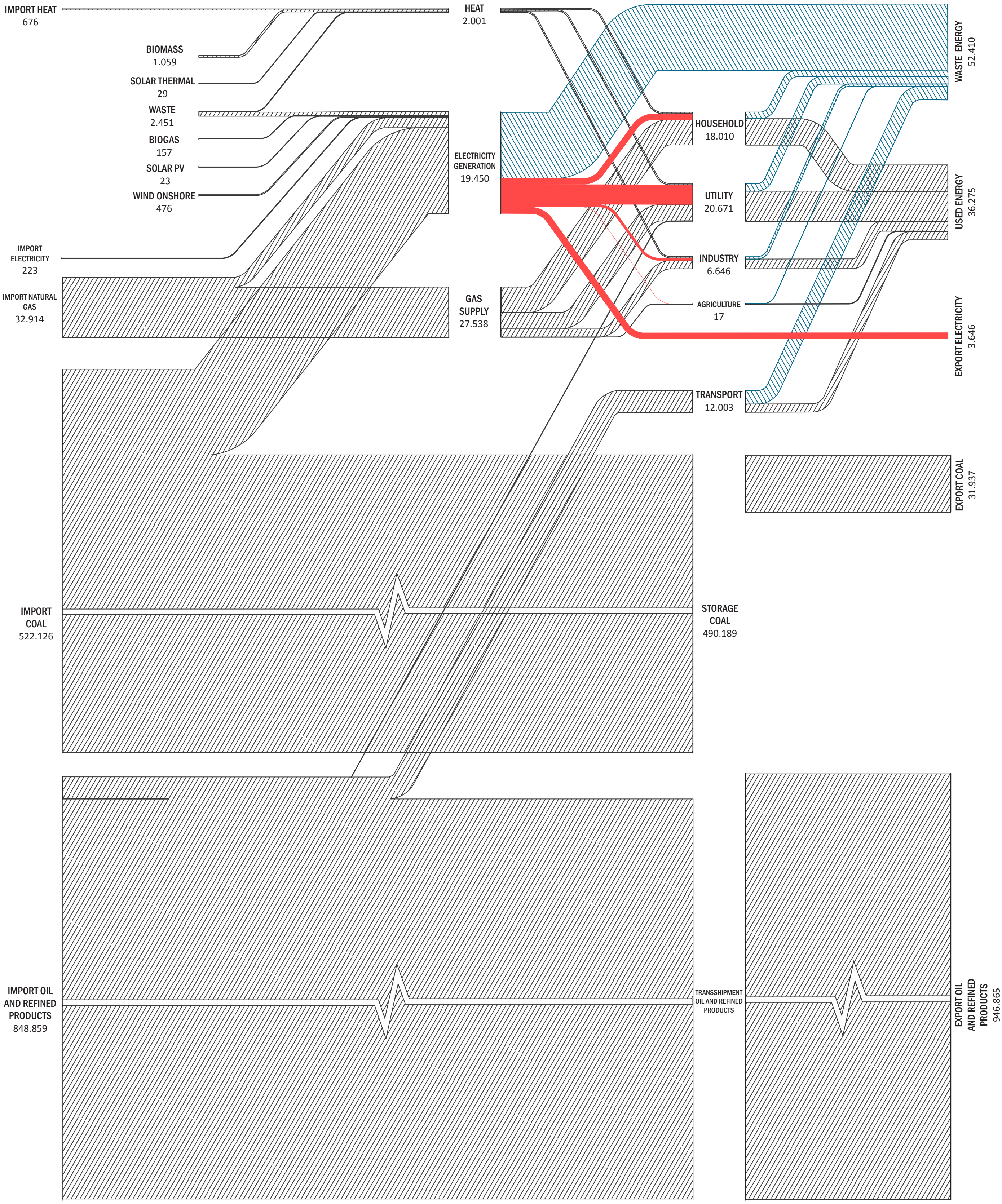


Figure 5.8 Energy balance of Amsterdam in 2012 [TJ]. The share of renewable energy generation compared to fossil fuel based energy generation is small. Coal and natural gas are still fundamental resources. Based on: Rijkswaterstaat (2012), Nuon (n.d.), Nuon (2013), Nuon (2014), Port of Amsterdam (2012) and CBS (n.d.).

8 (Nuon, n.d.). Subsequently 1.090.000 tons of coal was exported in 2012 (ibid), marking the port of Amsterdam as a large storage- and distribution hub for coal. Considering Amsterdam has no self-supply in natural gas, all consumed natural gas is imported. After coal, natural gas is the second largest energy input for electricity generation in Amsterdam. It is consumed by households, utility, industry and agriculture, as well as power plants for electricity generation. Power plants running on natural gas have a larger rate of return than power plants running on coal (ECN, 2007; CE Delft, 2011). Average efficiency of steam- and gas power plants is 58% (ECN, 2007), while the efficiency of coal power plant Hemweg 8 in particular is only 40% (CE Delft, 2011). These inefficiency rates suggest large 'waste energy' amounts representing conversion losses for electricity generation. Transhipment of oil and refined products is even bigger than transhipment of coal: over 19.514.000 tons of import, and over 21.767.000 tons of export (Port of Amsterdam, 2012). This larger export number is probably caused by supply of oil product storage not considered in the import number. 12.003 TJ (1,4% of the import) is consumed in Amsterdam. Remarkable is that the consumption sectors have larger dependency on natural gas rather than electricity. As a final outcome, the assumed amount of used energy is smaller than the amount of waste energy. This can be caused by large conversion losses and possible inefficiency and insufficiency in the use of energy. Here, efficiency deals with 'doing things right' whereas sufficiency deals with 'doing the right things' (Barrett et al., 2002, p.XV). For example electricity and gas can be used unnecessarily in households, utility and industry (inefficiency). Another example is remaining energy in the form of residual heat that is often not used and disposed (insufficiency), while residual heat can be considered as a sustainable substitute for room heating by gas and electricity.

Prospective energy balance

An interpretation of a prospective energy balance is given in order to show how Amsterdam's energy metabolism in 2040 could function in an improved way (Figure 5.9). The prospective energy balance is largely based on the CO_2 ambition document of Amsterdam (Zwijnenburg and Bosman, 2014). In general the document proposes green energy delivered by renewable energy sources, whereas less energy demand is present, with less energy conversion- and transport losses, resulting in a significant decrease of CO_2 emissions (Zwijnenburg and Bosman, 2014). Also ambitions from the document 'Amsterdam, an energy port in transition' (Port of Amsterdam, 2013) are used as input. Thus unlike the current energy balance, the prospective energy balance is not a diagram based on specific measured numbers, but an interpretation of qualitative ambitions.

Nowadays Amsterdam's electricity demand is approximately 15.800 TJ per year. Only 2.870 TJ of that delivered electricity is from renewables. Therefore exploitation of various renewable energy sources should be extended, preferably having complete electricity generation by renewables. The port of Amsterdam has an ambition to make a large transition in their vast coal transhipment: from coals to biomass (Port of Amsterdam, 2013). To decrease unnecessary energy consumption by inefficient buildings, the utility sector should have at least energy label B (out of a range from A – economical, till G - inefficient). Transition towards energy label B will constitute decreased energy demand. The decrease in Dutch energy consumption would be approximately

30% in 2040 (Greenpeace and EREC, 2013, p.58). Additionally, all buildings being constructed from 2015 should be climate neutral. Furthermore the transportation sector should be green as well: only electricity and biofuel can be the prospective fuels for (public) transport. Biofuel is already being produced in the port of Amsterdam: for example an amount of 334,8 TJ was produced in 2012 (Rijkswaterstaat, 2012). The port of Amsterdam desires to make a gradual transition in their transhipment of oil: a transition to biofuel in the future would fit better in a world of

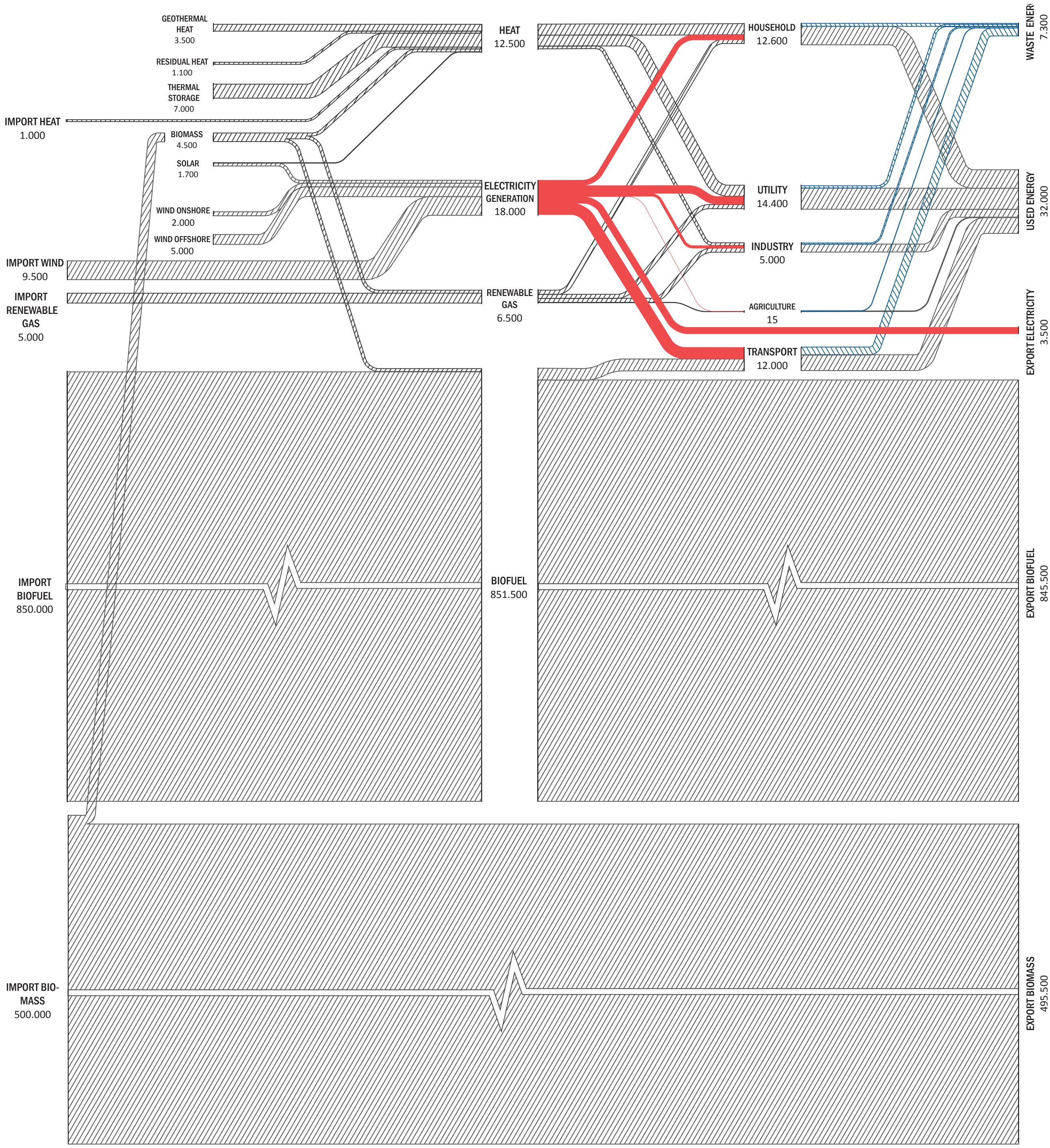


Figure 5.9 Prospective energy balance of Amsterdam in 2040 [TJ]. Renewable energy assimilation takes over fossil fuel based energy. Transhipment transitions from oil to biofuel and from coal to biomass will be made. Based on: Zwijnenburg and Bosman (2014), Port of Amsterdam (2013) and Greenpeace and EREC (2013).

renewable energy (Port of Amsterdam, 2013). Thermal networks, especially district heating should be extended and connected to more buildings in order to decrease the electricity and gas demand used for space- and water heating. Considering the large demand for natural gas, renewable gas can be the renewable substitute. Renewable gas extracted from biomass is already being produced in the port, for example 157,4 TJ in 2012 (Rijkswaterstaat, 2012). The final outcome of the energy balance should exist of more used energy than waste energy: the opposite of the current energy balance.

5.3 Energy consumption and potential analysis

The energy consumption- and potential analysis aims to discover which city districts have relatively high and low energy demand, and which districts therefore can sustain other districts with renewable energy potentials. The result is a theoretical energy balance among districts: gaps and opportunities in renewable energy delivery can be revealed. First an inventory of the energy demand per district is conducted, subsequently districts with approximately the same energy demand are mapped. Then a renewable energy potential analysis per district is showed. Finally, the mapped energy consumption- and potentials per district are compared; revealing where theoretical 'shortages' and 'surpluses' of energy are located when Amsterdam will fully rely on renewable energy. This outcome is essential for prescribing energy-conscious strategies for Amsterdam.

5.3.1 Energy consumption

The energy consumption of districts is analysed in order to identify low-demanding areas and high demanding-areas in terms of energy. A fundamental document called 'CO_2-uitstoot rapportage 2009' (Klimaatbureau Amsterdam, 2011) is used for the energy consumption inventory because it gives specific numbers of electricity- and gas consumption in the fifteen districts (Table 5.2). A more recent CO_2 emission report giving numbers for 2011 is found, however it lacks information about energy consumption in specific districts. The fifteen districts analysed are administrative borders from before the 1st of May 2010. Nowadays Amsterdam is organized in eight simplified districts. Numbers for electricity- and gas consumption are measured. But numbers for consumption of transportation fuels were not found in the CO_2 emission report 2009. That is why the transport consumption per district is based on the average fuel consumption per capita, in order to still suggest an interpretation of the fuel consumption per district. The average fuel consumption per capita is derived from the total fuel consumption (paragraph 5.2.2) and the population of Amsterdam. The energy consumption for transport per capita is then 0,015 TJ per year (Appendix 4). Subsequently the energy consumption per capita is multiplied with the amount of inhabitants per district. Appendix 4 describes how this calculation is made. Important to be aware of is that numbers of inhabitants per district are in total smaller than the total current population: 754.358 inhabitants compared with 810.937 (CBS, 12 December 2014). This smaller amount is caused by the older configuration of city districts. Also the total population of Amsterdam kept increasing during the years. To make the energy consumption inventory representative for both amount of inhabitants and numbers of consumption, energy consumption

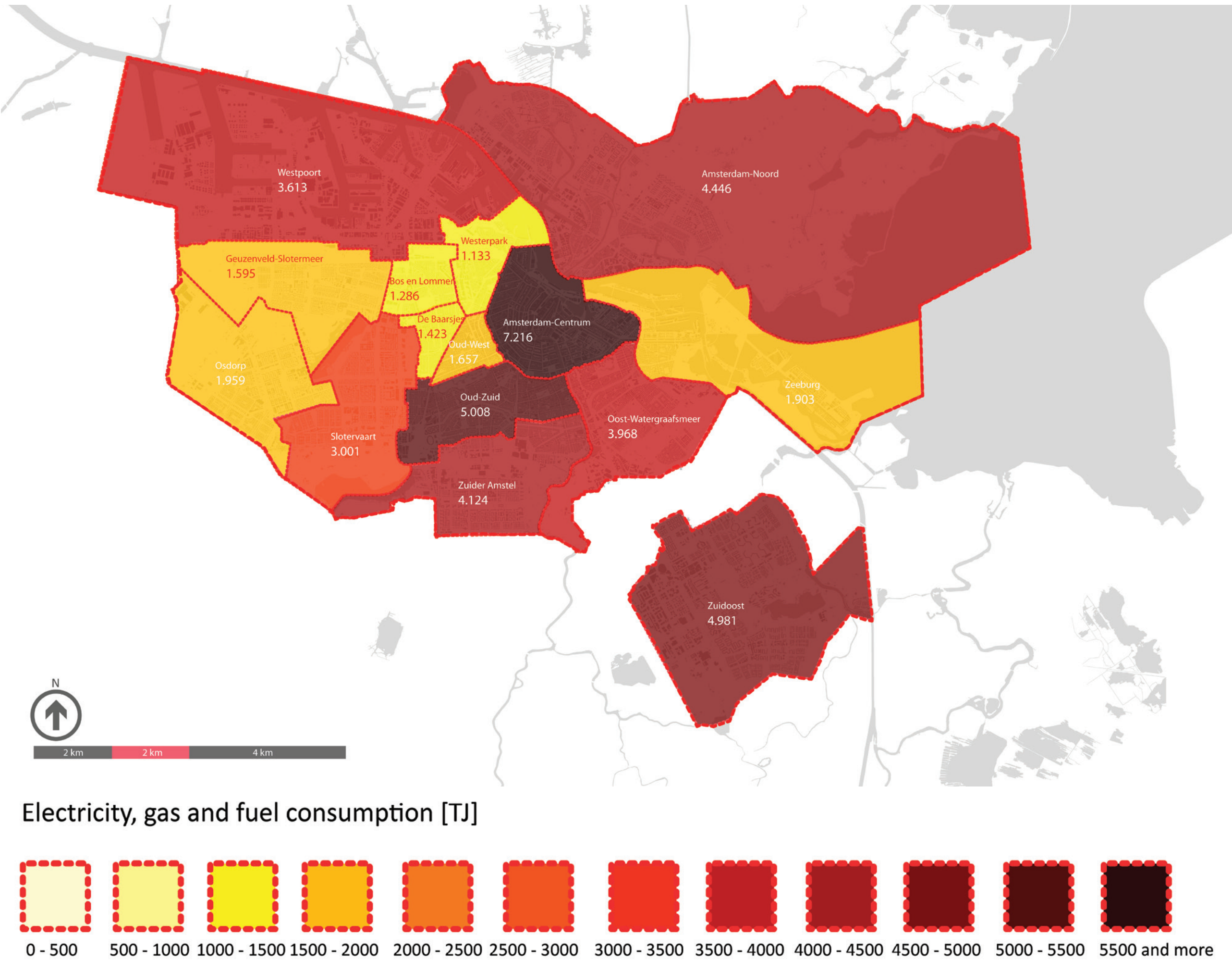


Figure 5.10 Energy consumption of 15 districts, based on 'CO2- uitstoot rapportage 2009' (Klimaatbureau Amsterdam, 2011).

Table 5.2 Energy consumption of 15 districts, specified in electricity-, gas-, and fuel consumption. The total consumption per district is outlined. Based on Klimaatbureau Amsterdam (2011, p.11-12).

Consumption per district (2009)

Source: CO2-uitstoot rapportage 2009 (publication: 2011)

District	Electricity *Electricity GWh*	TJ	Gas *Gas x million m3*	TJ	Transportation TJ	**Total consumption** TJ	Consumption per km2 [TJ]
Amsterdam-Centrum	639	**2.300,4**	118	**3.714,64**	**1.200,5**	**7.215,6**	856,37
Amsterdam-Noord	284	**1.022,4**	68	**2.140,64**	**1.282,9**	**4.445,9**	71,23
Westpoort	626	**2.253,6**	43	**1.353,64**	**5,5**	**3.612,7**	102,70
Zuidoost	519	**1.868,4**	59	**1.857,32**	**1.255,3**	**4.981,0**	229,92
Oost-Watergraafsmeer	288	**1.036,8**	66	**2.077,68**	**853,5**	**3.968,0**	369,64
Zeeburg	137	**493,2**	20	**629,60**	**780,0**	**1.902,8**	95,99
Geuzenveld-Slotermeer	75	**270,0**	23	**724,04**	**601,0**	**1.595,0**	154,41
Osdorp	103	**370,8**	29	**912,92**	**675,3**	**1.959,0**	177,25
Slotervaart	303	**1.090,8**	40	**1.259,20**	**651,3**	**3.001,3**	257,35
Bos en Lommer	65	**234,0**	19	**598,12**	**453,8**	**1.285,9**	458,51
Westerpark	105	**378,0**	24	**755,52**	**504,1**	**1.637,6**	387,93
De Baarsjes	55	**198,0**	23	**724,04**	**501,0**	**1.423,0**	827,90
Oud-West	85	**306,0**	28	**881,44**	**469,8**	**1.657,2**	936,71
Oud-Zuid	295	**1.062,0**	86	**2.707,28**	**1.238,8**	**5.008,1**	698,17
Zuider Amstel	306	**1.101,6**	74	**2.329,52**	**692,5**	**4.123,6**	396,42
Subtotal	3885	**13.986**	720	**22.665,60**			
Additional consumption*		1.573,20		4155,36			
Total	4.322	**15.559,2**	852	**26.820,96**	**11.165,3**	**47.816,9** TJ excl. Additional consumption*	
						53.545,43 TJ incl. additional consumption	

* Additional consumption: some consumption is directly linked to a company.
For privacy reasons these numbers are not available in public for specific districts.

numbers from 2009, with a district configuration from 2009 are used for the inventory.

Amsterdam-Centrum has the highest energy consumption in total of all districts (see Figure 5.10). But Oud-West has the largest energy consumption per km2 (Table 5.2). For both districts the high number is probably caused by high intensity utility functions, but also the age of buildings. Monumental merchant houses and warehouses are often lower in energy efficiency than more modern buildings. After Amsterdam-Centrum, Oud-Zuid is the second largest energy consumer in total. Bos en Lommer, Westerpark and De Baarsjes have the lowest energy demand in total, but this is caused by the small size of these districts. Zeeburg, Osdorp and Geuzenveld-Slotermeer for example have a much larger surface and not significantly more energy demand. Westpoort with its industry has probably a bigger energy consumption than shown in Table 5.2. This is because 'additional consumption' (Table 5.2) is not taken into the districts. Additional consumption is namely only given as a total number, not indicated per district (Klimaatbureau Amsterdam, 2011, p.11). Because 'additional consumption' is for the most part from industry, Westpoort probably has a larger consumption than in Table 5.2. Amsterdam-Noord has by far the biggest district surface of 62,4 km2. But because of limited amounts of buildings in the east, Amsterdam-Noord has approximately the same energy demand as Zuider Amstel, Zuidoost and Oost-Watergraafsmeer. Thus the energy consumption depends on the amount and intensity of consumers per district. This means that for example smaller districts with low intensity buildings (e.g. dwellings) and therefore a low total energy demand compared with other districts are not necessarily efficient- or energy-conscious consumers.

The total consumption is approximately 53.545 TJ in 2009 of electricity, gas and fuels. This total consumption is approximately 3.700 TJ less than the total consumption showed in the Sankey diagram from 2012 (paragraph 5.2.2.1). A possible reason is increased energy demand due to increased population compared with 2009.

5.3.2. Introduction on the potentials

In the Energy Atlas various renewable energy potentials are mapped (den Boogert et al., 2014, p.46-72). Figure 5.11, 5.12 and 5.13 show which mapped potentials were used in paragraph 5.3.3. Seven out of eleven mapped potentials in Amsterdam have the most promising theoretical amounts of energy:

- Open cold-heat storage: 108.000 TJ (50/50 split: 54.000 TJ heat and 54.000 TJ cold)
- Geothermal heat: 9.300 TJ
- Closed cold-heat storage: 8.000 TJ (50/50 split: 4.000 TJ heat and 4.000 TJ cold)
- Solar: 3.750 TJ
- Wind: 1.600 TJ
- Domestic waste: 1.100 TJ
- Residual heat: 160 TJ

Cold-heat storage in Amsterdam has a high potential. Cold-heat storage is basically an underground system of tubes, a liquid in the tubes serves as a transport medium for cold and heat. Buildings attached to cold-heat storage systems can extract heat in winter and cold in summer in order to reach a pleasant temperature for spaces and water. Cold-heat storage can occur in two ways: open and closed. In an open system, ground water from aquifers is extracted, infiltrated and

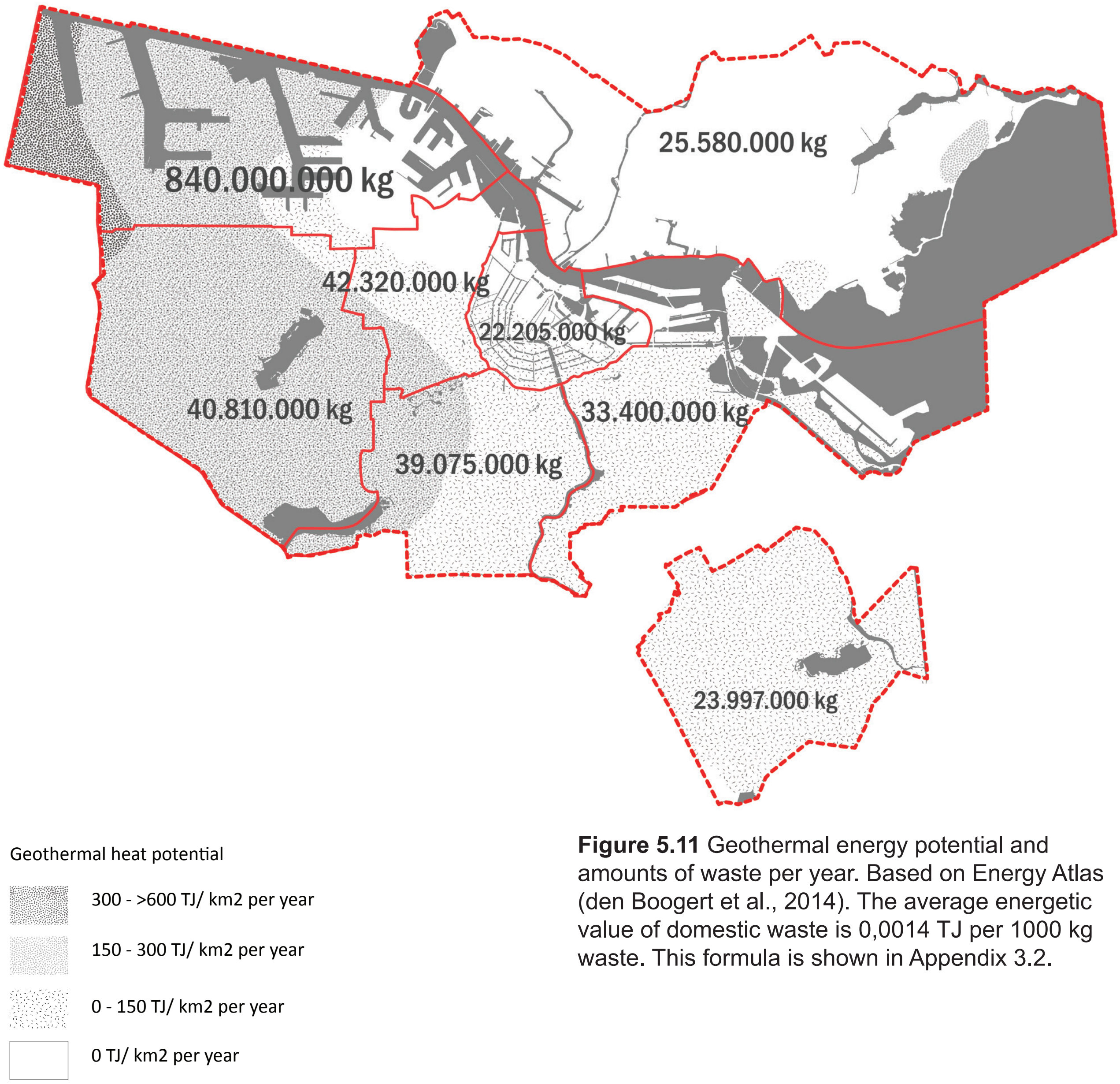


Figure 5.11 Geothermal energy potential and amounts of waste per year. Based on Energy Atlas (den Boogert et al., 2014). The average energetic value of domestic waste is 0,0014 TJ per 1000 kg waste. This formula is shown in Appendix 3.2.

returned by special pipes. A closed system is an underground system of tubes as well but does not extract and return water in the soil: the network is literally closed and not in contact with ground water. Both open- and closed systems are calculated with a monosource as a starting point (den Boogert et al., p.76-77). This is a system where 'hot' and 'cold' aquifers are connected with one (mono) system, whereas the desired temperature of the liquid is adjusted by means of a heat exchanger. In summer demand for cooling is present, cool water is extracted from the 'cold' aquifer, whereas hot water is returned in the 'hot' aquifer.

In summer, hot water is extracted from the 'hot' aquifer, cool water is returned in the 'cold' aquifer. Open cold-heat storage has in Amsterdam a much higher thermal storage capacity than closed cold-heat storage (den Boogert et al., 2014). Preconditions however are that connected buildings to cold-heat storage must require relatively low heating temperature. Proper insulation is then needed. Also there has to be a cold- and heat demand simultaneously, in order to keep the cold-heat system in balance. When this balance is lost, the system will lose its function (den Boogert et al., p.58). Geothermal heat has in Amsterdam

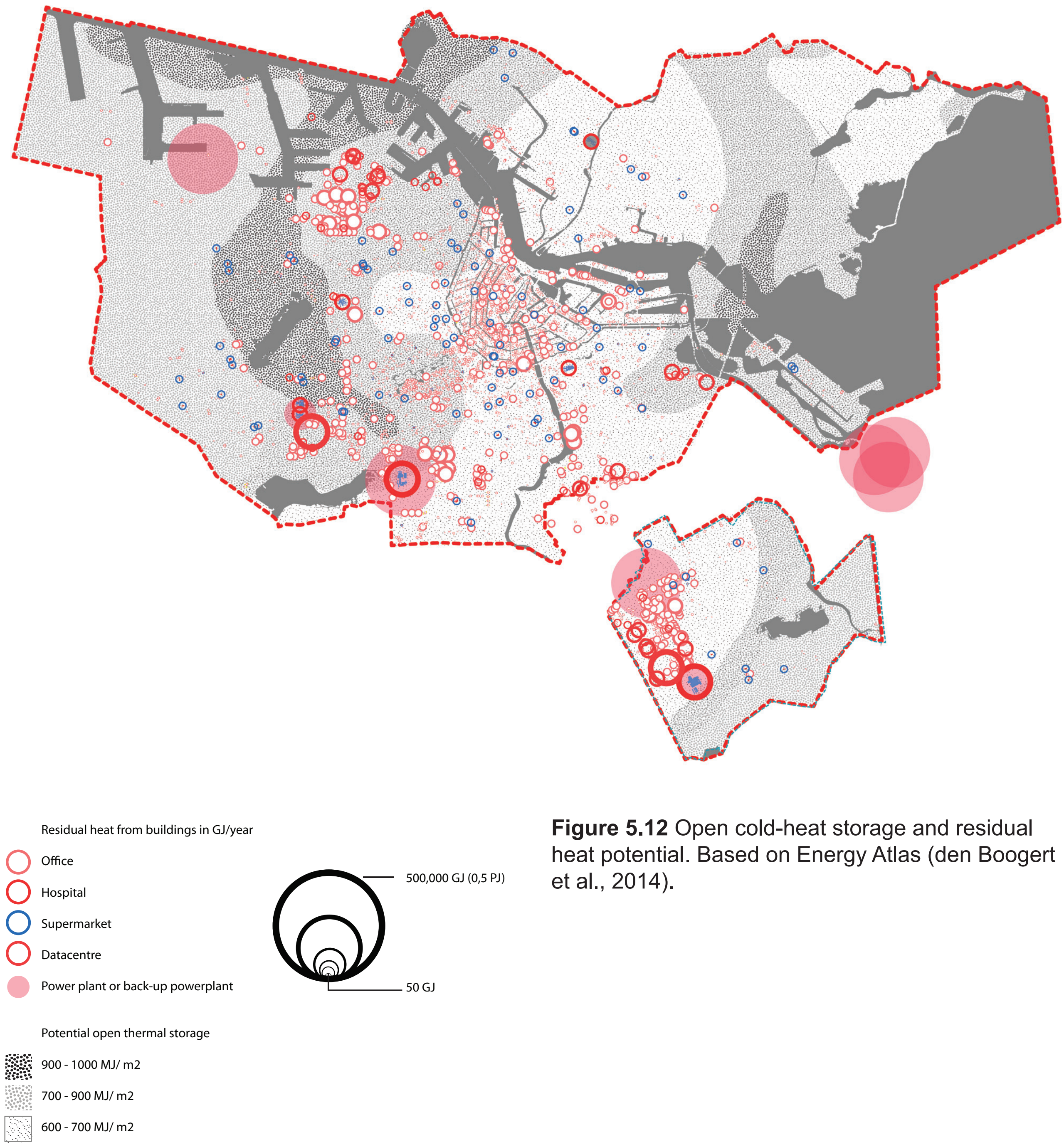
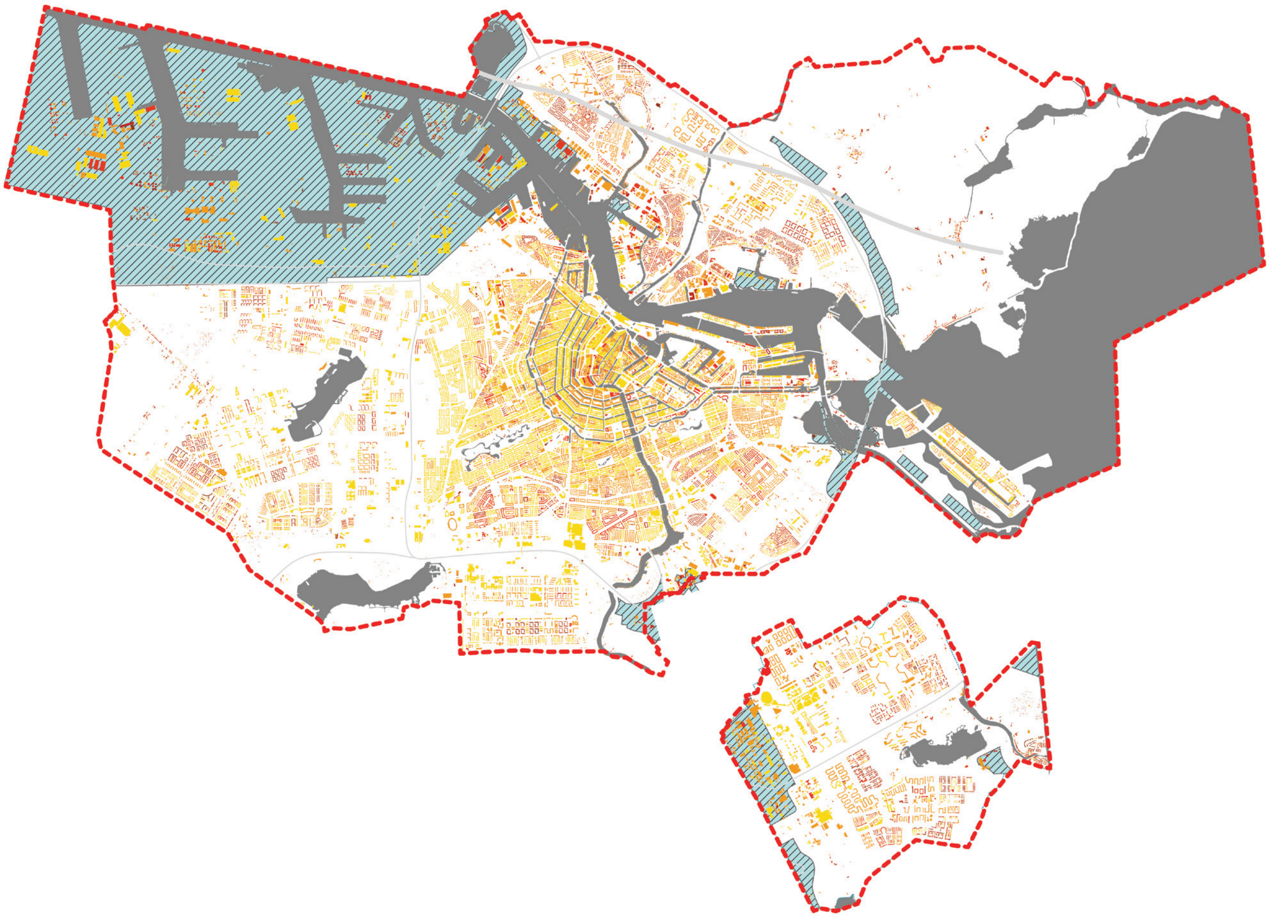


Figure 5.12 Open cold-heat storage and residual heat potential. Based on Energy Atlas (den Boogert et al., 2014).

a high potential as well. Geothermal heat is also extraction of thermal energy but unlike cold-heat storage heat is extracted from hot soil temperatures deep below ground (groundwater is not involved). Potential solar energy is based on suitable roofs in Amsterdam that have sufficient orientation towards south and a suitable surface where solar panels are easy to install. Potential of wind energy considers large wind turbines, where many restrictions are attached to. The theoretical potential is dramatically decreased due to minimum required distance of 300 m from buildings. Also restrictions such as height of wind turbines around Schiphol airport or view and casting shade are taken into account.



Solar potential per year per m2 of surface area

- 1 - 22 kWh
- 22 - 38 kWh
- 38 - 56 kWh
- 56 - 86 kWh
- 86 - 108 kWh

Potential areas for wind turbines

Figure 5.13 Potential areas for large scale wind turbines of 3 MegaWatt and 7,5 MegaWatt, and solar energy on roofs. Based on Energy Atlas (den Boogert et al., 2014).

Domestic waste is being processed by AEB whereas waste is converted into energy. All bio-based waste is possible to be processed for energy: 98% electricity and 2% heat (ibid). Finally the potential of residual heat is able to add heat to the heating network. Residual heat coming from offices, datacenters, hospitals and supermarkets are considered for the potential.

5.3.3. Renewable energy potentials districts

Potentials per district are calculated for six types: wind, solar, open heat-cold storage, waste, residual heat and geothermal heat. Appendix 3 shows all datasheets made for the potentials. Closed cold-heat storage (mentioned in paragraph 5.3.2) is not taken into account because this type of thermal storage has much less potential compared with open thermal storage. The potentials wind, solar and open cold-heat storage were able to be calculated with ArcGIS. From the other three potentials data was not available. Residual heat and geothermal heat were manually calculated with maps form the Energy Atlas (2014). For geothermal heat, average values per district were identified (derived from map colours), whereas the energy potential is estimated by means of the legend on the map. Residual heat potential is estimated by manually counting residual heat units on the map (units larger than 0,5 TJ). Data for domestic waste was gathered at the particular interactive map on maps. amsterdam.nl. Subsequently the waste amounts of kg per district taken into a formula for potential energy from waste. This formula is elaborated in the Energy Atlas (den Boogert et al., 2014).

Large scale wind turbine potentials are the biggest in Westpoort (Figure 5.14). Because industry is the main function here, restrictions for wind energy are very low. Zuidoost has the second highest potential for wind turbines. Amsterdam-Noord would have at first sight large potential because of an open agricultural area. However this area called Waterland is not considered as potential for wind energy (see Figure

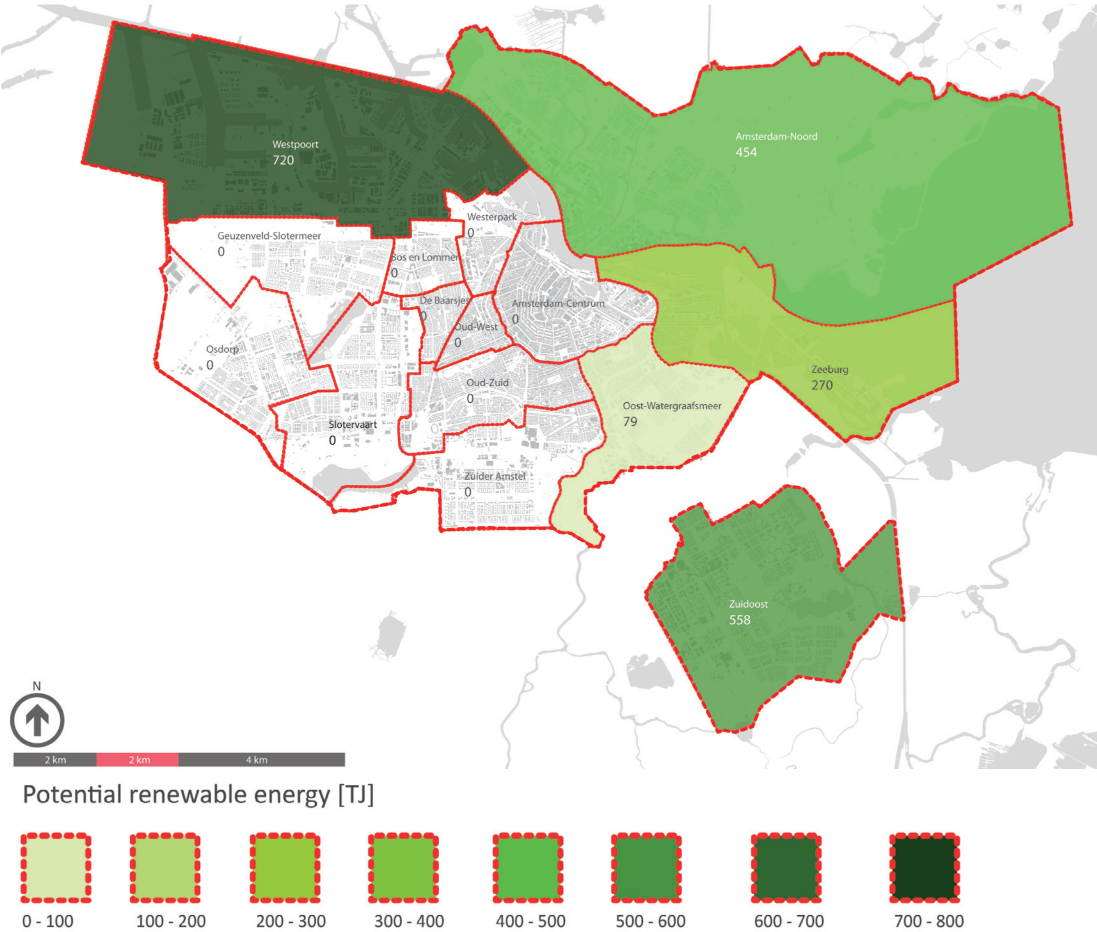


Figure 5.14 Renewable energy potential of large scale wind turbines of 3 MegaWatt and 7,5 MegaWatt. Based on: den Boogert et al., 2014, p.50-51, an ArcGIS shapefile received from Laura Hakvoort (DRO Amsterdam) and an Excel datasheet (Appendix 3.1).

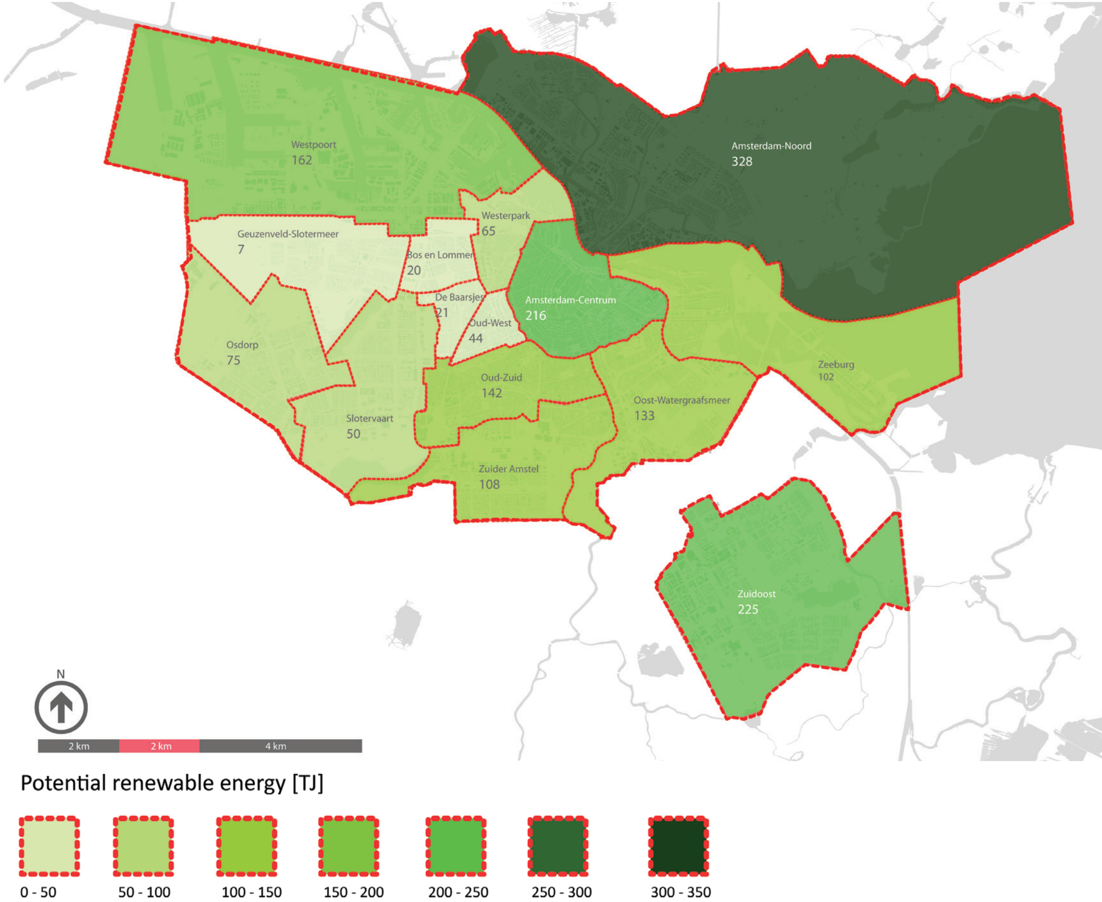


Figure 5.15 Renewable energy potential of solar radiation on roofs. Based on: den Boogert et al., 2014, p.48-49, an ArcGIS shapefile received from Laura Hakvoort (DRO Amsterdam) and an Excel datasheet (Appendix 3.1).

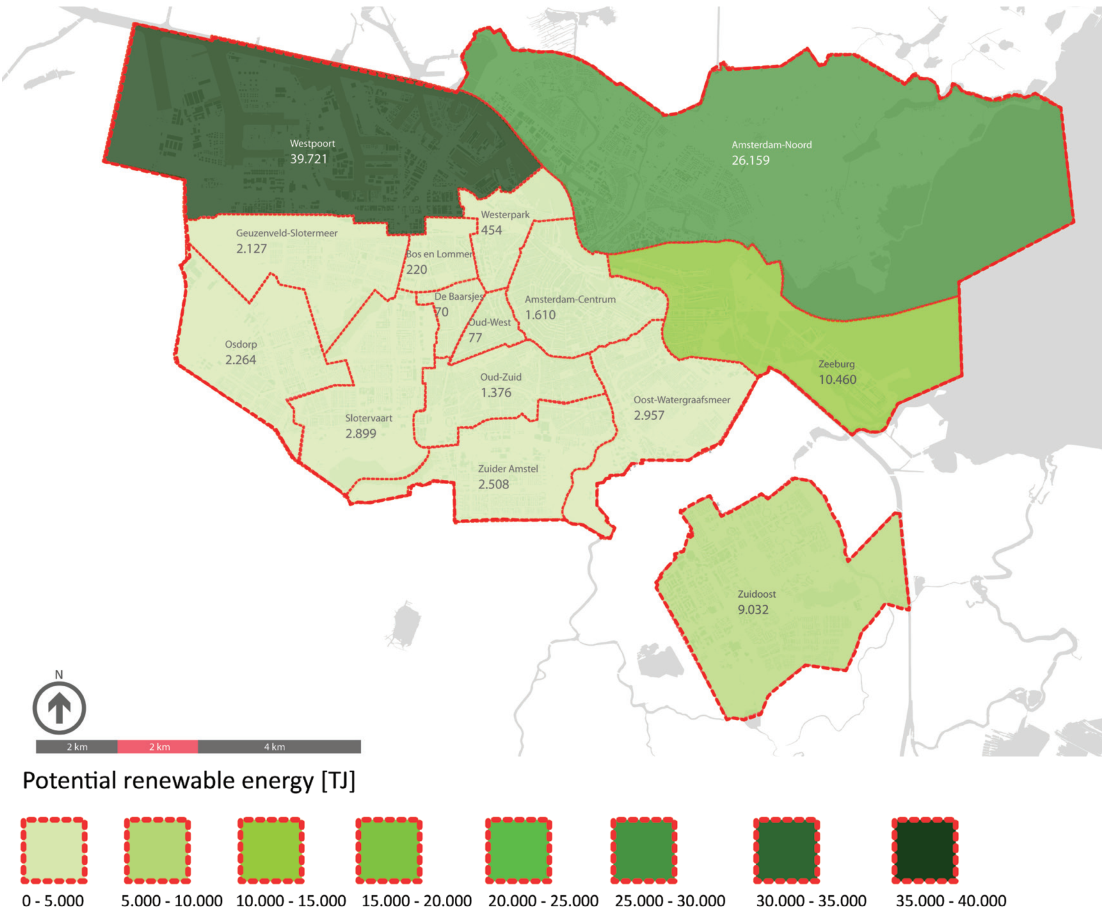


Figure 5.16 Renewable energy potential of open cold-heat storage. Based on: den Boogert et al., 2014, p.58-59, an ArcGIS shapefile received from Laura Hakvoort (DRO Amsterdam) and an Excel datasheet (Appendix 3.1).

5.13). Probably because of aesthetic-, historical and ecological values of the area. In the Energy Atlas (2014) possible wind energy on open water (Markermeer) is not taken into account. Off-shore wind however can be attractive for large-scale electricity generation not directly visible on land.

Solar energy potential is highest in Amsterdam-Noord because this district has the most suitable roofs for solar PV. Zuidoost has the second largest potential for solar energy (Figure 5.15).

Open thermal storage has highest potential in Westpoort (Figure 5.16). This potential per district depends not only on district size, but also on suitability of soils per district. Although there is a theoretical potential for all districts, it is important to remind that buildings in older neighbourhoods (such as Amsterdam-Centrum, Oud-Zuid and Oud-West) are likely to be unsuitable for connection with thermal storage. As mentioned earlier, a requirement for using thermal storage efficiently is a relatively low demand for space heating. Older buildings might have insufficient insulation then.

Westpoort also has the largest potential in energy from waste. Westpoort as a port and industrial area produces lots of waste compared with other districts (see Figure 5.17). An advantage is that waste energy company AEB is located in Westpoort whereas large waste productions are in proximity to the processing location.

Residual heat has the highest potential in Zuidoost, Zuider Amstel and Westpoort (Figure 5,18). In Zuidoost especially back-up power plants and data

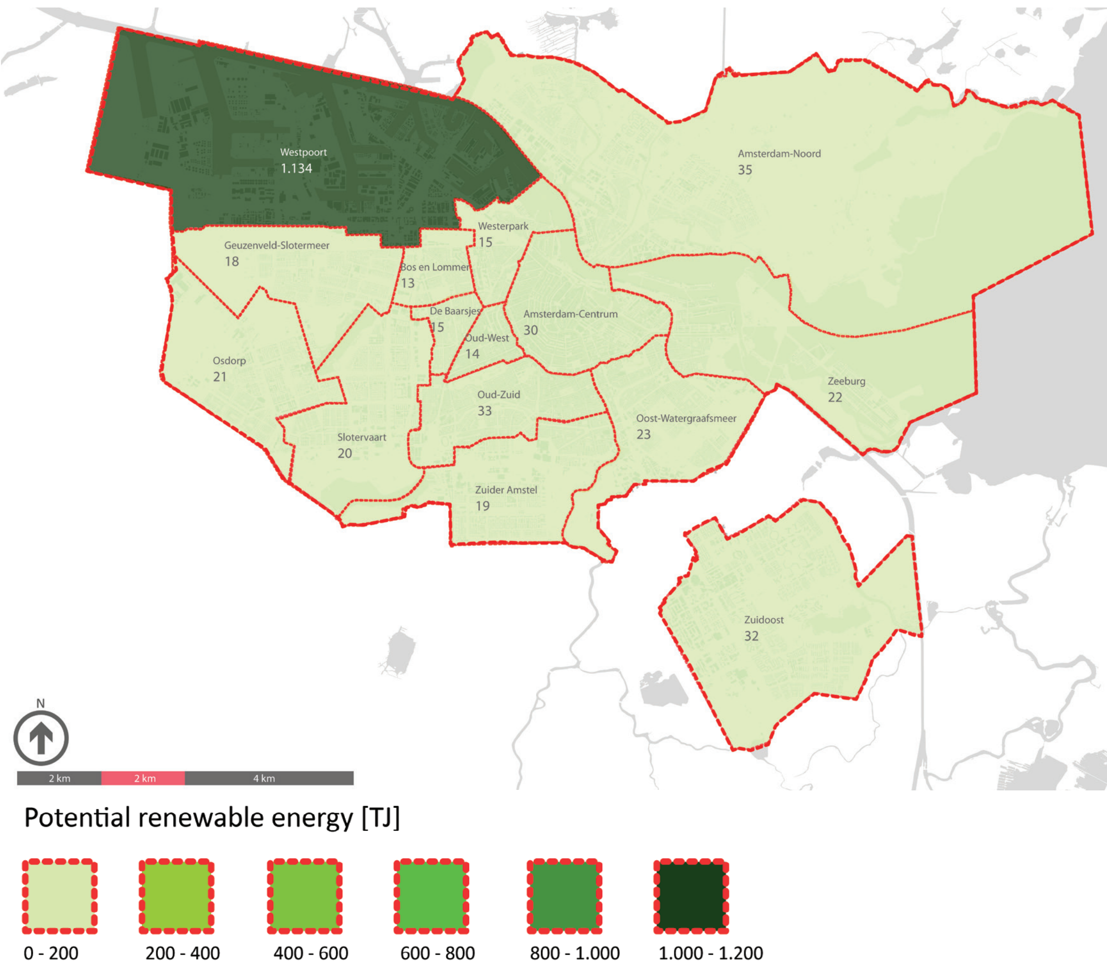


Figure 5.17 Renewable energy potential generated from waste, based on waste output per district. Based on: den Boogert et al., 2014, p.66-67, maps.amsterdam.nl and an Excel datasheet (Appendix 3.2).

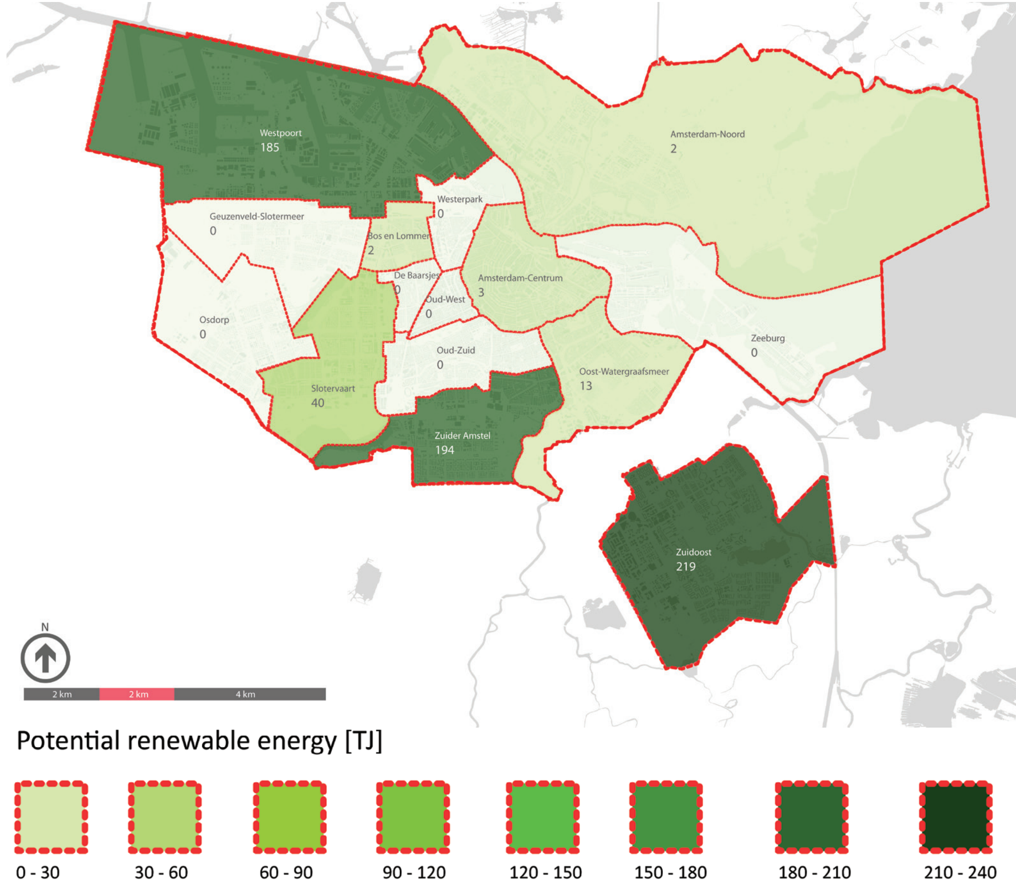


Figure 5.18 Renewable energy potential of residual heat. Based on: den Boogert et al., 2014, p.64-65 and an Excel datasheet (Appendix 3.3).

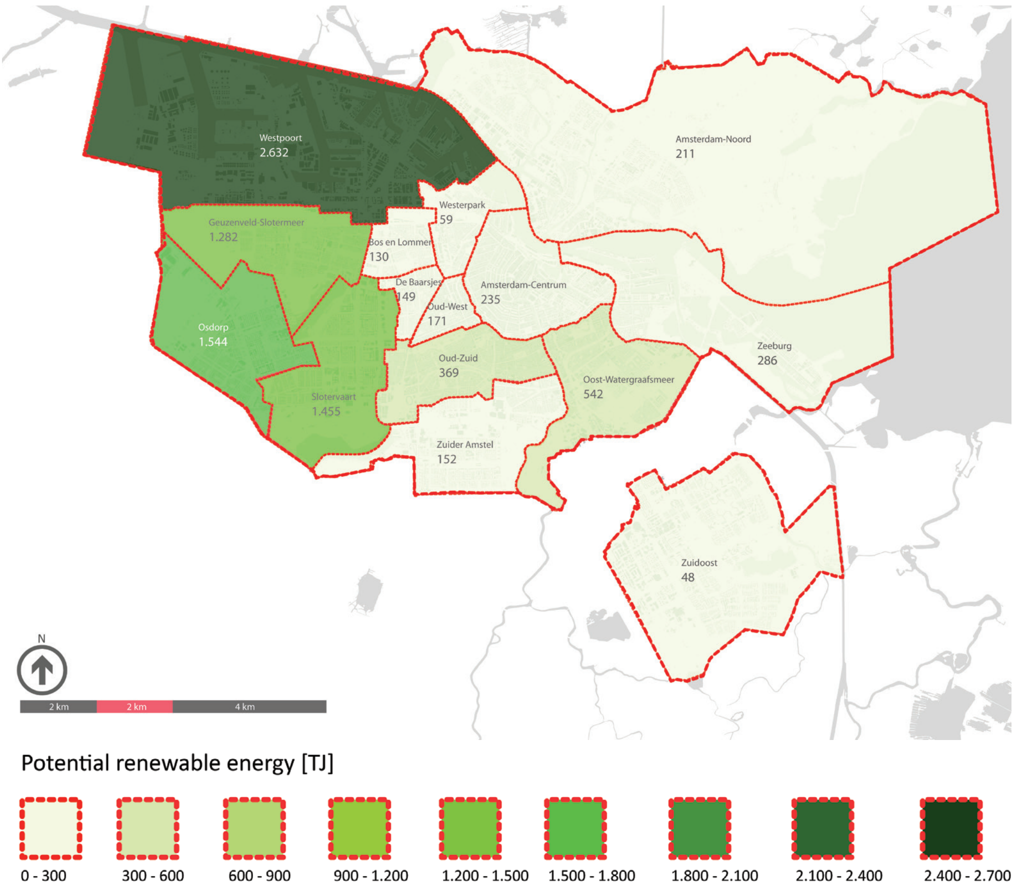


Figure 5.19 Renewable energy potential of geothermal heat. Based on: den Boogert et al., 2014, p.62-63 and an Excel datasheet (Appendix 3.3).

centres are important sources of residual heat. In Zuider Amstel the most important source is a back-up power plant as well. The largest heat supplier of Westpoort is AEB. Some data centres and offices also emit heat. Although the Hemweg power plant is not mapped as a potential heat supplier, it certainly has a large potential. Hemweg might have a similar heat potential as the Diemen power plant, approximately 500 TJ per year.

The districts Westpoort, Osdorp, Slotervaart and Geuzenveld-Slotermeer could be considered as a high-delivering cluster of geothermal heat (Figure 5.19). Just like thermal energy storage it depends highly on the soil how many energy can be extracted from geothermal heat. An example of a geothermal heat installation is showed in Figure 5.20. Expanding a thermal network requires reshaping of the urban landscape (Figure 5.21) that can earn itself back when appropriate locations are chosen.

Considering all six renewable energy potentials together, Westpoort is by far the district with the largest potentials (Figure 5.22). Westpoort has the highest potential in wind, open cold-heat storage, waste and geothermal heat. It is also the district with the most potential per km2 (Table 5.3). Amsterdam-Noord has the highest potential in solar energy, and Zuidoost has the largest potential in residual heat. Amsterdam-Noord has no significant potentials compared with other districts, except for solar energy and open heat-cold storage. The calculations of the potential analysis per district suggest promising numbers in open cold-heat storage. However if this application is really able to be fully exploited by the urban districts in Amsterdam is the question. Depending on the amount of buildings that seem suitable for connection with a district heating- and cooling network, investments in time and money can be a failure or success. Off-shore wind energy is not considered in the Energy Atlas (2014), but it might have outstanding potential for electricity generation.

Figure 5.20 Example of an installation extracting geothermal heat from the soil. Source: www.conserve-energy-future.com.

Figure 5.21 A district heating- and cooling network in construction. It exists if insulated tubes filled with a liquid as thermal energy carrier. Source: www.ceequal.com.

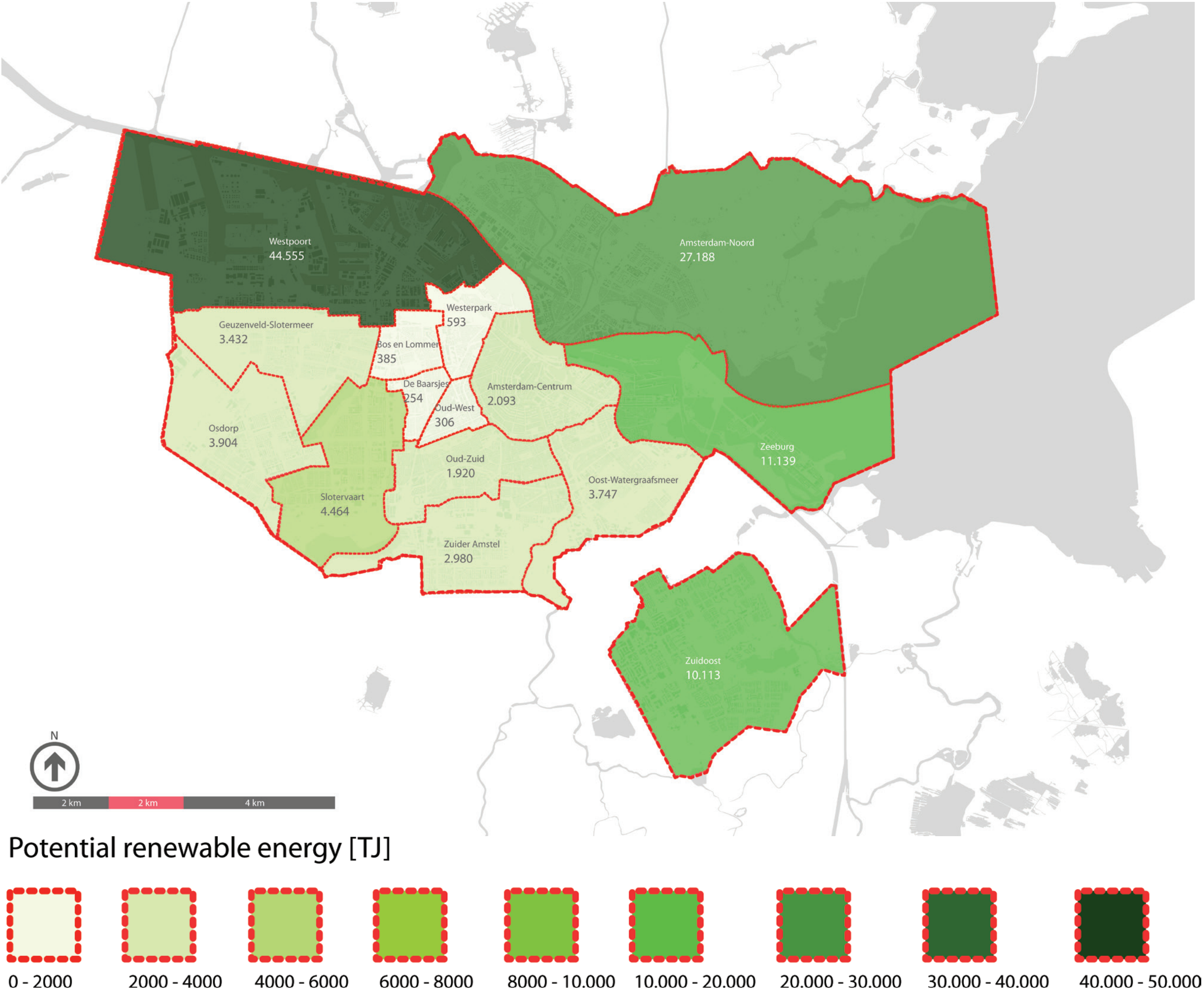


Figure 5.22 Total renewable- and residual energy potential potentials per district, accumulated.

Table 5.3 Total renewable- and residual energy potential potentials per district. The largest potential per km2 is district Westpoort: 1.266 TJ. Zeeburg carries the second largest potential per km2: 562 TJ.

District	Wind	Solar	Open heat-cold storage*	Waste	Residual heat	Geothermal heat	**Total**	**Potential per km2 [TJ]**
Amsterdam-Centrum	0	215,65	1.610,16	30,0	3,34	234,53	2.093,7	248,5
Amsterdam-Noord	453,6	328	26.159,08	34,5	1,67	211,33	27.188,2	435,6
Westpoort	720	162,28	39.721,08	1.134,0	185,48	2.632,13	44.555,0	1.266,6
Zuidoost	558	225,07	9.031,84	32,4	218,90	47,65	10.113,9	466,9
Oost-Watergraafsmeer	79,2	133,4	2.956,73	23,0	13,37	541,61	3.747,3	349,1
Zeeburg	270	101,95	10.459,67	21,9	0	286,36	11.139,9	562,0
Geuzenveld-Slotermeer	0	6,66	2.126,86	17,6	0	1.281,73	3.432,8	332,3
Osdorp	0	75	2.263,82	21,4	0	1.543,79	3.904,0	353,2
Slotervaart	0	49,78	2.899,18	19,9	40,10	1.455,95	4.464,9	382,8
Bos en Lommer	0	20,19	219,82	13,4	1,67	130,44	385,6	137,5
Westerpark	0	65,12	454,44	14,8	0	59,29	593,7	140,6
De Baarsjes	0	20,7	69,53	14,8	0	149,33	254,3	148,0
Oud-West	0	43,67	77,26	14,1	0	171,29	306,3	173,1
Oud-Zuid	0	142,28	1.376,43	33,2	0	368,93	1.920,9	267,8
Zuider Amstel	0	107,53	2.507,73	18,9	193,84	152,26	2.980,3	286,5
[Diemen power plant]					501,3			
Total [TJ]	2.080,8	1.697,3	101.933,6	1.444,0	1.159,7	9.266,6	117.080,7	
Total excl. Diemen [TJ]					658,374			

* Open heat-cold storage: total amount of potential is distributed among 50% cold and 50% heat
This means 50.997 TJ heat and 50.997 TJ cold

5.3.4. Energy consumption vs. potential

When the energy consumption- and potential per district were calculated and mapped, a comparison is made (Figure 5.23). With this comparison theoretical 'surpluses' and 'shortages' among the fifteen districts are identified. These theoretical surpluses and shortages (Table 4) are applicable in a hypothetical situation where Amsterdam fully relies on the six previous mentioned renewable energy sources, considering the energy consumption from 2009.

Remarkable is that a cluster of districts with an energy shortage is surrounded by districts with an energy surplus (Figure 5.24). Theoretically some districts will do just fine enough on their own, while other districts have a significant surplus. Amsterdam-Centrum has the biggest energy shortage, caused by a consumption that is the largest of all districts combined with not enough potential in renewable energy. Westpoort seems to have the biggest opportunity in becoming a major renewable energy supplier. Looking at the numbers Amsterdam-Noord can also contribute as a major renewable energy supplier, but much of the district is outside proximity of the densely populated region. Large transport distances of energy can constitute energy losses, depending on the energy carrier: for example transport distance of hot water is limited compared to electricity (Stremke and Koh, 2010). Eventually the 'ring' of 'surplus' districts could sustain the cluster of 'shortage' districts with renewable energy.

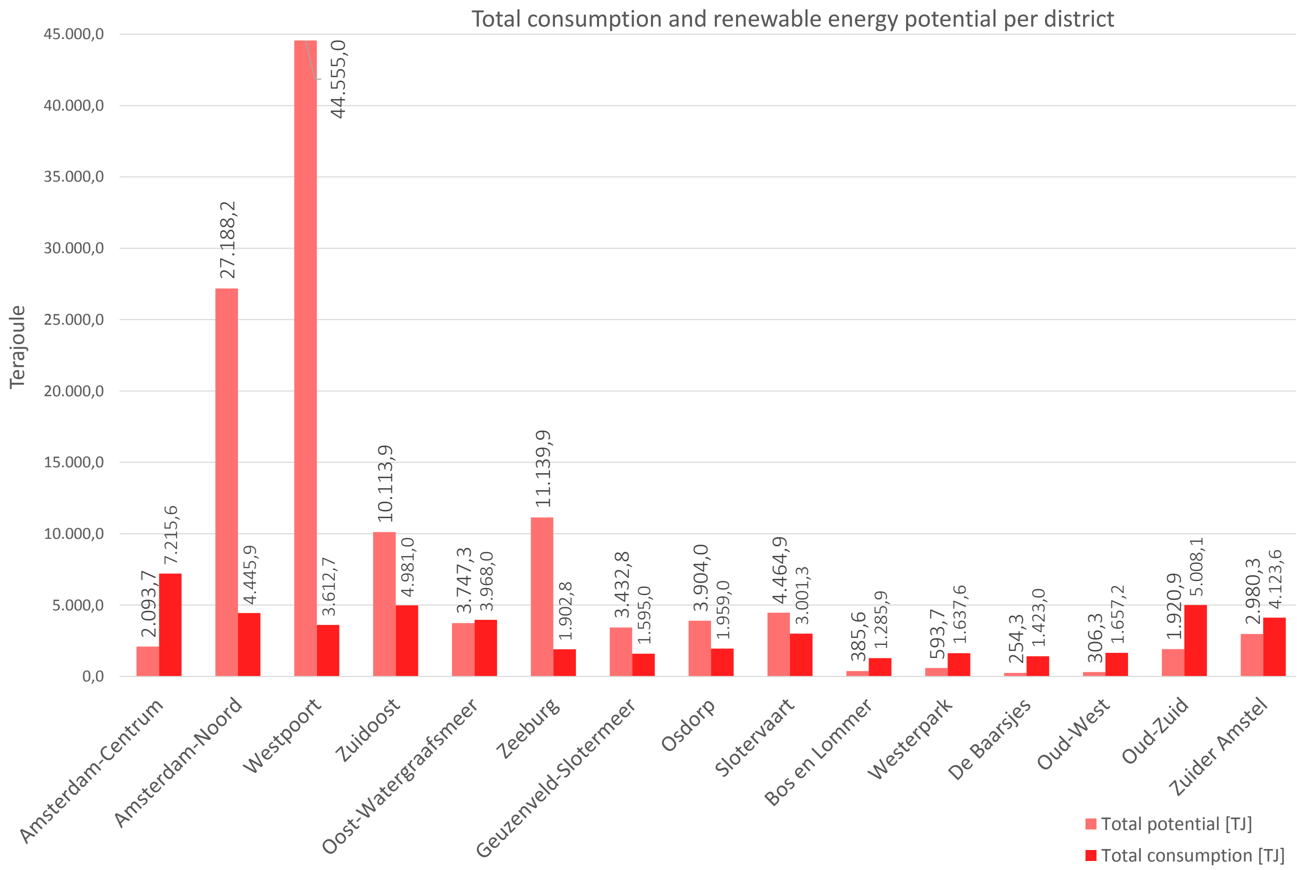


Figure 5.23 Comparison of energy consumption- and total potential of all renewables together per district.

Table 4 Theoretical surplus and shortage of energy per district [TJ].

District	*Consumption*	*Potential*	*Surplus(+)*	*Shortage(-)*
Amsterdam-Centrum	7.215,6	2.093,7		-5.121,9
Amsterdam-Noord	4.445,9	27.188,2	22.742,3	
Westpoort	3.612,7	44.555,0	40.942,3	
Zuidoost	4.981,0	10.113,9	5.132,9	
Oost-Watergraafsmeer	3.968,0	3.747,3		-220,7
Zeeburg	1.902,8	11.139,9	9.237,1	
Geuzenveld-Slotermeer	1.595,0	3.432,8	1.837,8	
Osdorp	1.959,0	3.904,0	1.945,0	
Slotervaart	3.001,3	4.464,9	1.463,6	
Bos en Lommer	1.285,9	385,6		-900,4
Westerpark	1.637,6	593,7		-1.043,9
De Baarsjes	1.423,0	254,3		-1.168,7
Oud-West	1.657,2	306,3		-1.351,0
Oud-Zuid	5.008,1	1.920,9		-3.087,2
Zuider Amstel	4.123,6	2.980,3		-1.143,3
Total	47.816,9	117.080,7	83.300,8	-14.037,0
Theoretical balance		+	69.263,8	

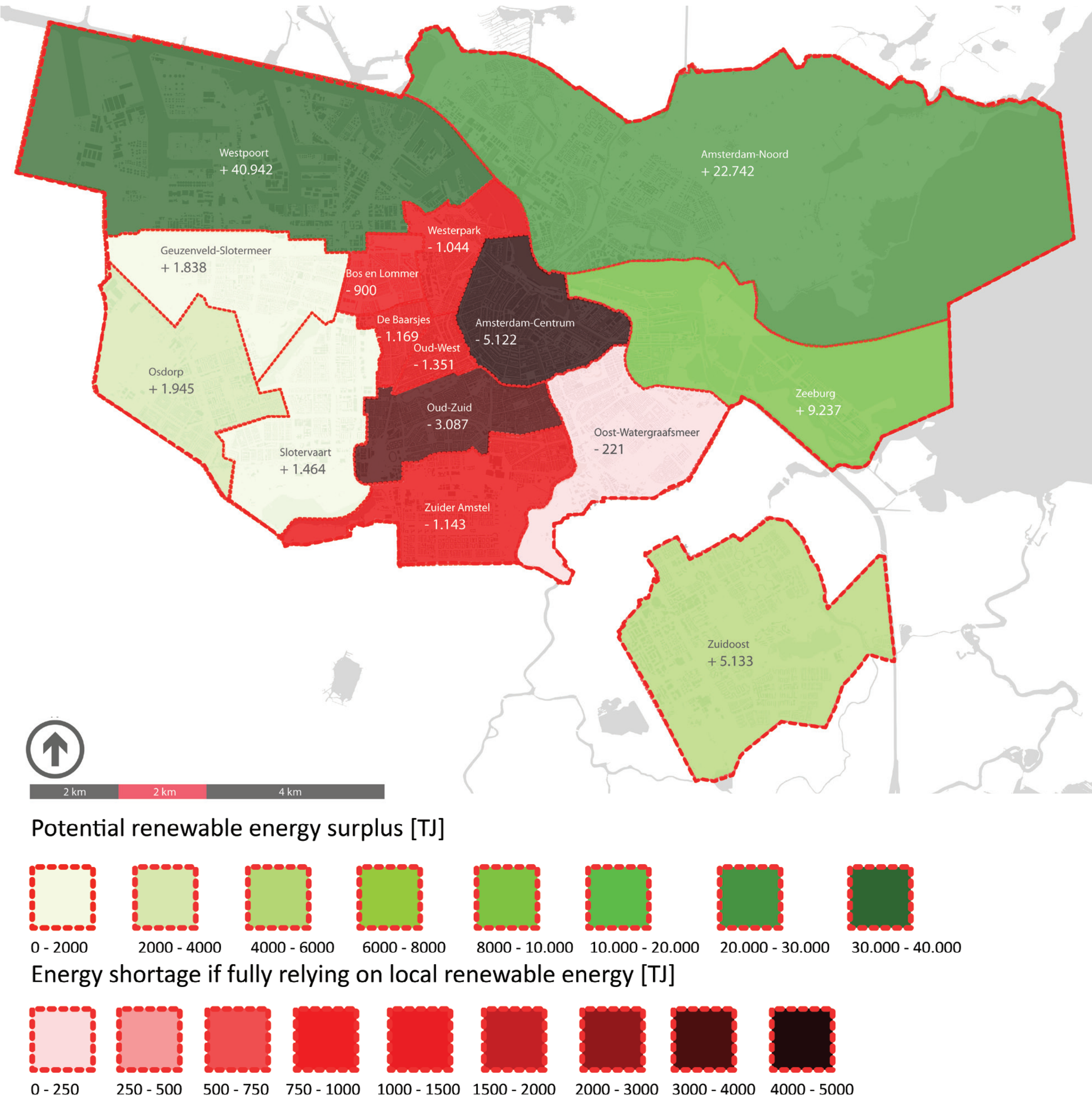


Figure 5.24 An 'energy shortage' cluster can be sustained by a surrounding 'energy surplus' ring.

5.4 Conclusions

Three topics were identified for the findings of the analysis: renewable energy assimilation, energy flows and energy consumption.

5.4.1 Renewable energy assimilation

There are huge potentials for renewable energy assimilation per year, especially for these potentials:

1. Open cold-heat storage: 102.000 TJ;
2. Geothermal heat: 9.000 TJ;
3. Wind energy: 2.000 TJ.

There are also additional renewables with a lower potential per year:

4. Solar energy: 1.700 TJ;
5. Energy from waste: 1.400 TJ;
6. Residual heat: 1.100 TJ.

In a global city perspective solar energy in total has not a significant potential, but locating it at buildings might be useful at the local building-scale in making self-sufficient buildings. Biomass from trees and shrubs is not taken in the analysis due to the highly urbanized land-use. Thus all biomass from trees and shrubs can be processed together with biomass from domestic waste in a centralized cogeneration plant (CHP). In districts (such as Zuidoost) where high-graded residual heat occurs in proximity to low graded heat, heat transfer can be useful (e.g. heat from datacentres to dwellings). Amsterdam-Noord has a low density population in the east. Distanced from the dense public network in the city, 'stand-alone' systems (Stremke, 2010) in this area can be considered in order to prevent energy transportation losses. This area also has much space for renewable energy assimilation on neighbourhood scale, such as wind parks or solar pv plants. The question however is if such a land-use claim is still needed when enough renewable energy is able to be generated elsewhere. It depends on the type of renewable energy source how profitable its implementation is. Although open cold-heat storage has the largest potential, it requires much work in constructing the network into the soil and connecting buildings to it. While wind- and solar energy can be installed directly above ground with not too many required changes in the urban fabric. Thus the question still is which renewable energy sources are most profitable and suitable for Amsterdam.

5.4.2. Energy flows

Some districts are theoretically self-sufficient in renewable energy, while other districts are not self-sufficient whereas they need additional energy. For this reason the 'ring' of 'surplus' districts (Figure 5.24) could sustain the cluster of 'shortage' districts, having energy flows towards the energy shortage cluster. Bio based waste can keep being processed by AEB for electricity- and heat generation. The idea 'from waste to energy' is an example of a symbiotic relationship between industry and offices or dwellings: waste goes to AEB and in return energy goes to consumers. Such symbiotic relationships are highly influential for reducing resource input and waste output, as well as more efficient resource cycling within the city. Producing waste however should not gain the identity of 'profitable resource', causing stimulation of increased waste production. District heating- and cooling networks already exist in some districts, but these networks are still quite limited. Therefore they can be expanded through neighbourhoods, particularly in those areas with high potential for open cold-heat storage. Next to thermal networks in suitable soils, thermal storage points distributed across Amsterdam can be connected to these networks. This could reduce transportation loss of thermal energy and increase reliability in heat- and cold supply. In districts where high-graded residual heat is emitted in proximity to areas with low-demanding heat functions (e.g. dwellings), heat cascading through thermal networks could be implemented. A common sequence for heat cascading is from power plants to industry, utility and dwellings (van den Dobbelsteen et al., 2009). In districts where only low-graded residual heat is emitted, small distance heat exchange between buildings can be considered (e.g. between supermarket and dwellings).

5.4.3. Energy consumption

Consumption intensity is often related to the age of a certain district: older districts are likely to consume more energy due to lower energy efficiency in buildings. Such districts have two options: rebuilding or retrofitting. With retrofitting, energy efficiency of existing buildings can be improved with e.g. better insulation in walls, double glazing, replacement of boilers or energy-efficient appliances (Barrett et al., 2002, p.97). With rebuilding, existing buildings are replaced by new bio-climatic and smart designed buildings that are more energy efficient. Temporal fluctuations (seasonal and daily) of energy demand requires reliable energy supply always ready to be utilized. When Amsterdam will fully rely on renewable energy, thermal energy storage can overcome fluctuations in heating and cooling demand. Next to thermal energy storage, reserves of biomass can be stored for generating electricity and additional heat. Huge amounts of cooling demand can be accommodated by trigeneration. Trigeneration is the same as cogeneration (electricity- and heat generation) except that generation of cooling is included (Chicco and Mancarella, 2009). Generating cooling is possible with renewable gas (ibid). Therefore existing power plants might be upgraded to trigeneration plants; supplying electricity, heating as well as cooling. The existing cooling network sourced by cold water from lakes can be expanded and fed by trigeneration plants. The port of Amsterdam has currently a large transhipment of oil and refined products: fuels. When Amsterdam makes a sustainable energy transition, the port of Amsterdam has the opportunity to become leading in biofuel and renewable gas. Renewable gas and biofuel then can be the new fuel for transport (next to electricity), whereas renewable gas can be the substitute for natural gas.

6. ENERGY-CONSCIOUS STRATEGIES APPLIED FOR AMSTERDAM

Chapter 6 identifies energy-conscious strategies that are applicable for Amsterdam, whereas the three topics addressed in conclusions of paragraph 5.4 are addressed in this chapter as well. The strategies are illustrated with indicative images which means they can be interpreted in various ways. Therefore they can be used flexibly for further planning and designing location oriented interventions. Generic strategies from Chapter 4 were combined into interventions that would fulfil multiple generic strategies. In an overall perspective, we recommend decreased needed input of energy, efficient energy utility by increasing exergy, reduced output of wastes and emissions, driven by local renewable energy to increase self-sufficiency.

6.1 Renewable energy assimilation

Renewable energy assimilation locally reduce input of fossil fuels as well as output formed by GHG emissions, reaching a more circular energy metabolism (Leduc and Van Kann, 2013, p.181). In medieval times and earlier, cities were in close proximity to renewable resources (Steel in Leduc and Van Kann, 2013, p.180). Since the industrial revolution fossil fuels became a dominant source of energy. Now it is possible to gradually make the switch back to renewable energy. On the metropolitan scale, clusters of various renewable energy sources (Figure 5.25, 5.26 and 5.27) are able to create a robust energy system that has high chance in energy supply (Stremke, 2008). Clusters can make strong source groups scattered in the municipality, reducing the distance between sources and sinks (ibid), and therefore reducing transport losses. Wind turbines can be expanded in marked areas for wind potential. Additionally, near-shore wind energy (Figure 5.25) is illustrated as an idea to be further investigated in order to increase renewable electricity supply within the municipality. Expansion of the heating- and cooling network can provide more buildings renewable heating and cooling (Figure 5.26). Power plants AEB and Diemen are already suppliers of district heating. Power plant Hemweg is indicated as additional supplier of district heating, which will sustain the expansion of the heating network. On district scale, geothermal heat and residual heat can be collected in one system, whereas heat exchangers or 'hubs' can distribute heat (Tillie et al., 2014, p.110). Expanding the heating- and cooling network requires investments in money and time. This thermal energy is able to substitute heating and cooling by gas and electricity in newer, already low-demanding buildings (den Boogert et al., 2014, p.58-59), but feasibility and yield in investments are still needed to be investigated. On the building scale, renewable energy assimilation can be considered to become partly self-sufficient in energy (Figure 5.28). Self-sufficiency in energy can increase saving in money, after the invested money is earned back. Self-sufficiency in the form of 'stand-alone' systems (Stremke, 2010, p.71) can be especially attractive for the low-density population of the rural area in Amsterdam-Noord, in order to prevent transport losses of energy.

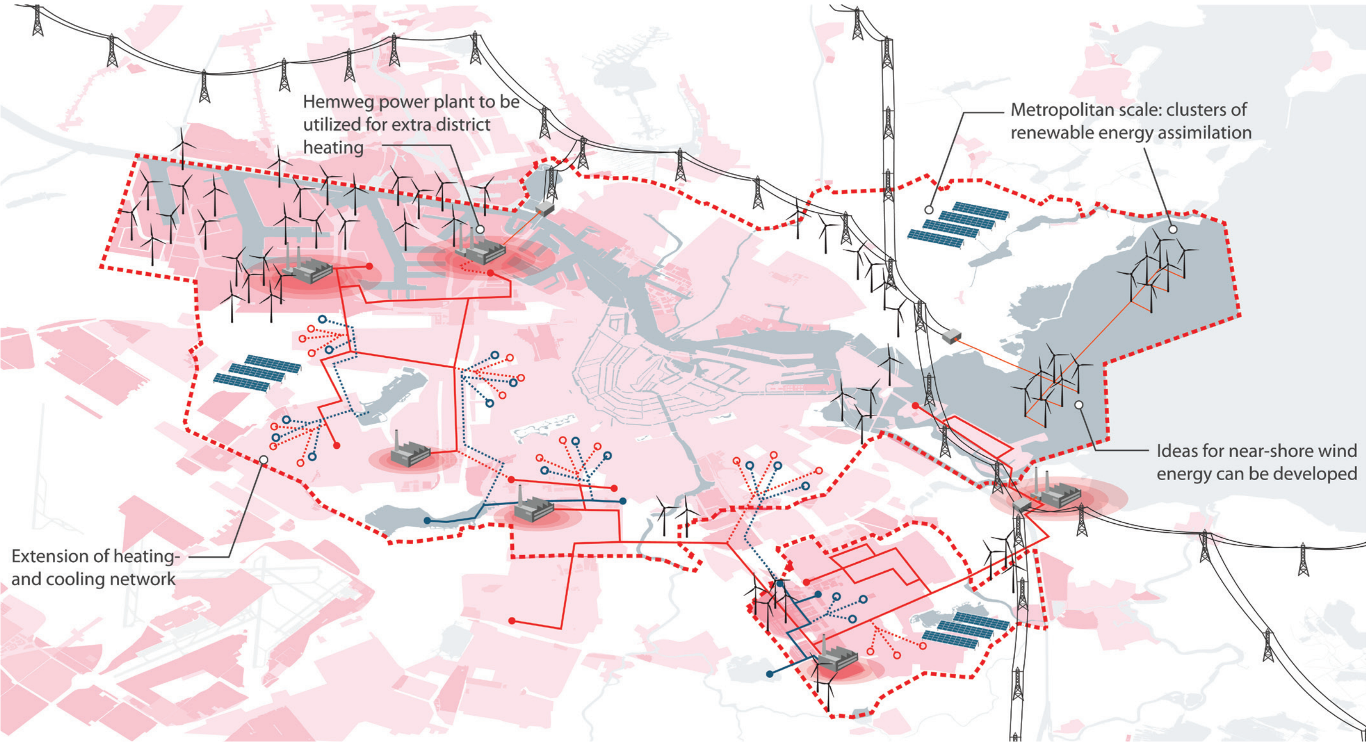


Figure 5.25 Various types of renewable energy assimilation are clustered and spread across the municipality, creating a robust energy system.

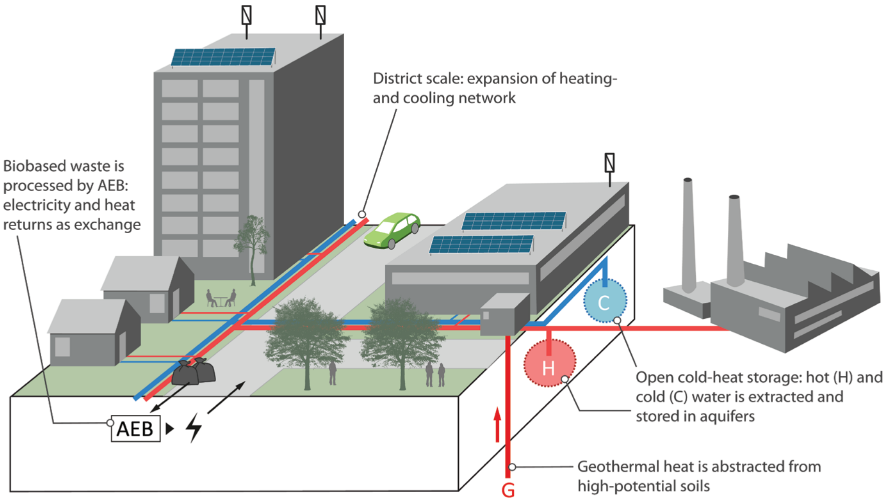


Figure 5.26 District scale: thermal networks are expanded, renewable energy assimilation takes place on smaller scale.

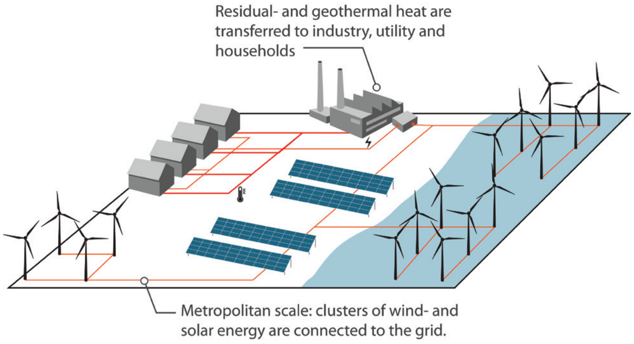


Figure 5.27 Near-shore wind could support onshore electricity demand. Desires and possibilities for large scale wind and solar PV can be investigated.

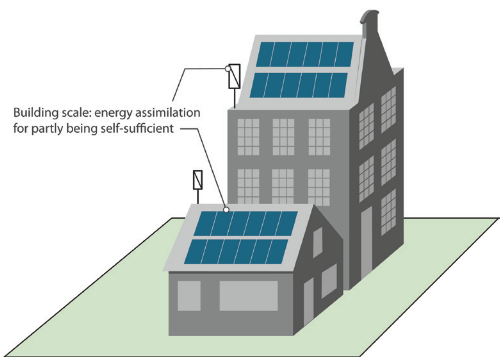


Figure 5.28 Renewable energy assimilation also on building scale.

6.2 Energy flows

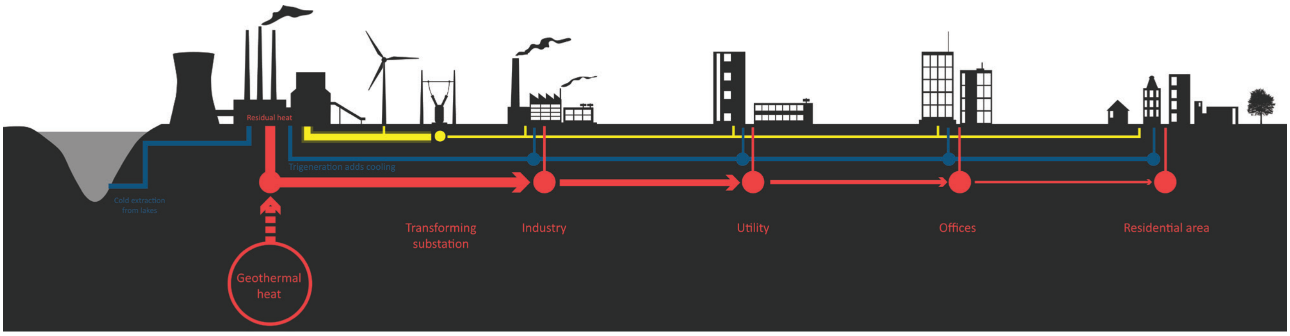


Figure 5.29 Heat existing of geothermal heat and residual heat can be added to the heating network and cascaded from power plants to industry, utility, offices and eventually residential areas.

As concluded from the case study, the ring of sources are theoretically able to sustain the cluster of sinks, which is suggested in Figure 5.30. The source areas are marked green and are areas where (in this case potential-) energy production exceeds the consumption (Stremke, 2010, p.35). A cluster of sinks is marked red and exists of areas where energy consumption exceeds the (potential) energy generation (ibid). District Westpoort is marked as a '++' area which means this district can be the most energetic source of renewable energy, calculated in the case study analysis. A symbiotic relationship (Chertow, 2007) is already happening between AEB in Westpoort and producers of waste. Waste is being transported to AEB, whereas bio based waste is processed and returned as energy in the form of electricity and heat (AEB Amsterdam, n.d.) shown in Figure 5.30. Searching for more symbiotic relationships can result in ideas for more circular flows in Amsterdam. Power plants could be upgraded to trigeneration plants: whereas the generation of cooling is added (Chicco and Mancarella, 2009, p.2). Together with extracted cold from deep lakes, trigeneration plants can feed the cooling network (Figure 5.29 and 5,30). In order to match the quality of energy -exergy- with a level that will suffice for a certain consumer and therefore avoiding energy loss (Leduc and Van Kann, 2008, p.3), cascading of heat is proposed (Figure 5.30). Geothermal heat from soil can be extracted and added to the heating network, also fed by residual heat from power plants. Subsequently the heat will 'cascade' through matching quality demanders as illustrated in Figure 5.29: to the sectors industry, utility, offices and eventually dwellings (van den Dobbelsteen et al., 2006, p.8). Thus the exergy of this flow of energy gradually decreases through the sectors, but will provide an exergy level that will suffice for all sectors. Remaining heat is able to return in the heating network.
In districts where low-graded heat is being emitted with no high-graded heat suppliers in proximity, heat exchange can be installed between building needing heat (Figure 5.31). A multi-functional land-use whereas thermal energy exchange is directly connected within building components would be even more efficient (Figure 5.32).

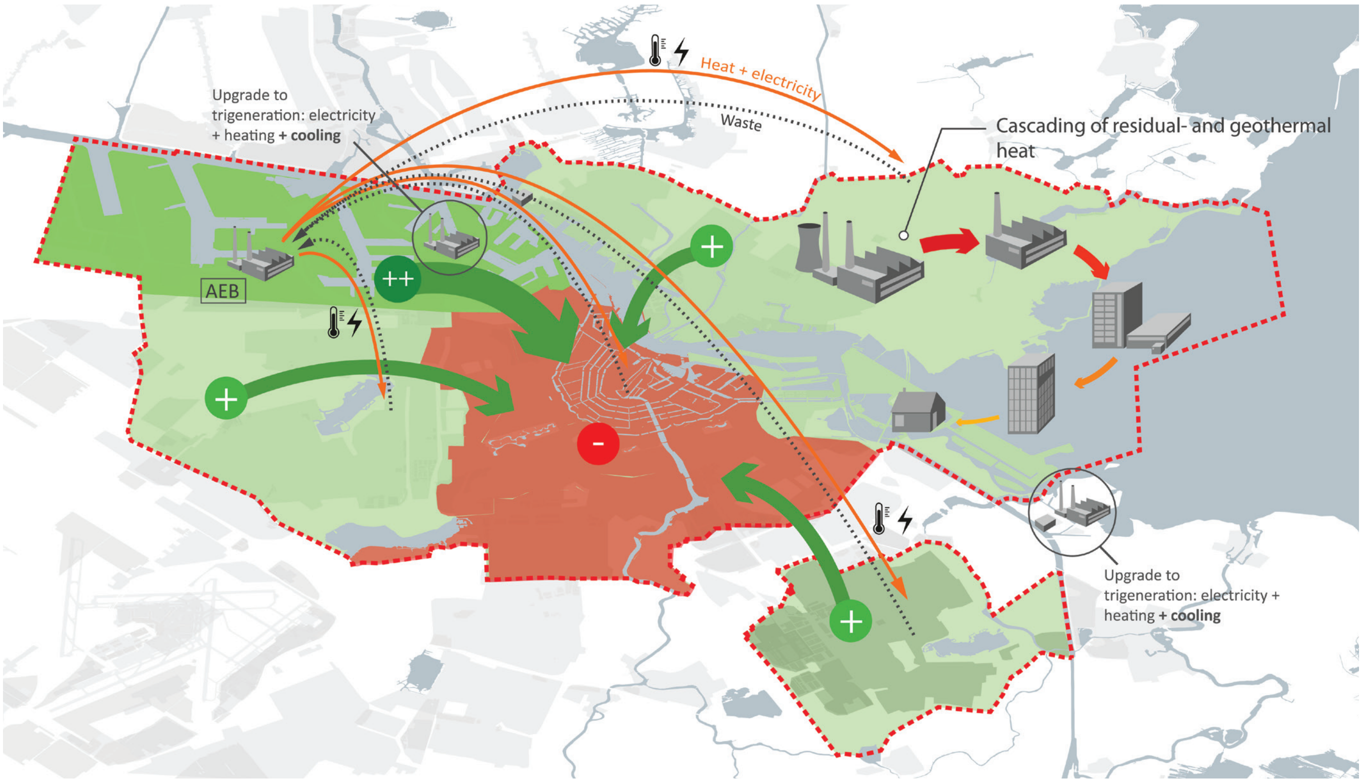


Figure 5.30 The red sink area can be sustained by the surrounding source area, whereas Westpoort can be the most energetic and innovative district. Searching for more symbiotic relationships (like the exchange between AEB and waste producers) can increase the city's metabolism efficiency significantly.

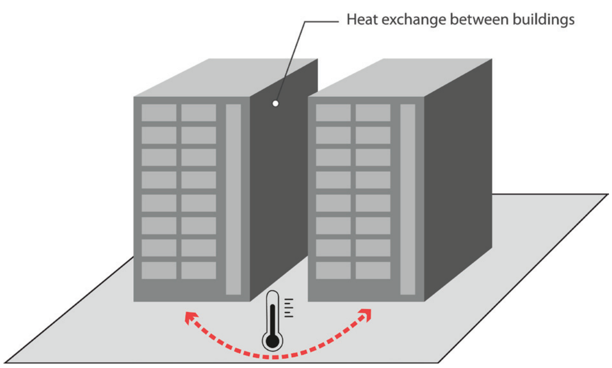


Figure 5.31 Heat exchange between buildings can be considered when high-graded heat is outside proximity. Rather than disposing residual heat in the air, exchange is a more sufficient alternative occurring between building close to each other.

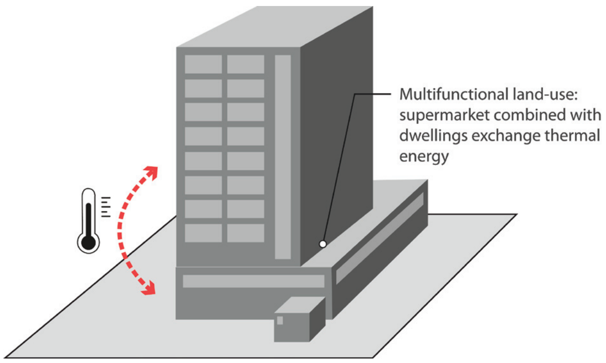


Figure 5.32 A mixed land-use with multiple functions constitutes an efficient thermal energy exchange.

6.3 Energy consumption

Stimulating efficient public transport connections for people and cargo reduces the need of cars within the densely populated city (Figure 5.33). Bringing work to living by reformulated, mixed land-use can even further decrease of transport by mobile means (Tillie et al., 2014, p.116-121). Cars can gradually make a transition to utility of fuels consisting of electricity and/or biofuel (Figure 5.33). Amsterdam already has more than 1.000 park- and charge points (Gemeente Amsterdam, 2014), and this amount keeps increasing, providing a future for electrified cars. Transport running on electricity and biofuels considers 'sufficient' energy consumption: 'doing the right thing' (Barrett et al., 2002, p.XV) in order to minimize GHG emissions. The sufficient energy consumption also applies on the building scale. This means being partly self-sufficient with renewables, whereas remaining needed energy comes from renewables as well. Various ways of becoming partly (or even completely) self-sufficient in energy on the building scale are illustrated in Figure 5.34. It depends on the soil (thermal energy) and the building itself which options are possible. Cogeneration applications are even available for homes in the form of micro CHPs (van den Dobbelsteen et al., 2009, p.19). Open thermal energy storage can overcome fluctuations in heating and cooling demand. In summer, cold water is extracted whereas hot water is returned. In winter, hot water is extracted whereas cold water is returned. When many options for consuming renewable energy by self-sufficiency are not possible (e.g. due to historical or monumental building aspects), unnecessary energy consumption can be avoided by retrofitting (Figure 5.35). Behaviour and energy-efficient appliances can reduce energy demand as well. There are even kinetic energy devices where electricity is generated from movement energy. For example fitness equipment in gyms, stairs, or a dance floor can be transformed in order to generate electricity by people in buildings.

Possibilities for behaviour vary from taking showers instead of baths, reducing thermostat temperature or turning off appliances when not in use (Barrett et al., 2002, p.106). With smart meters able to be installed by net maintainer Liander, direct insight in energy consumption is shown. Consumers then can become even more conscious in their energy use (Liander, 2014).

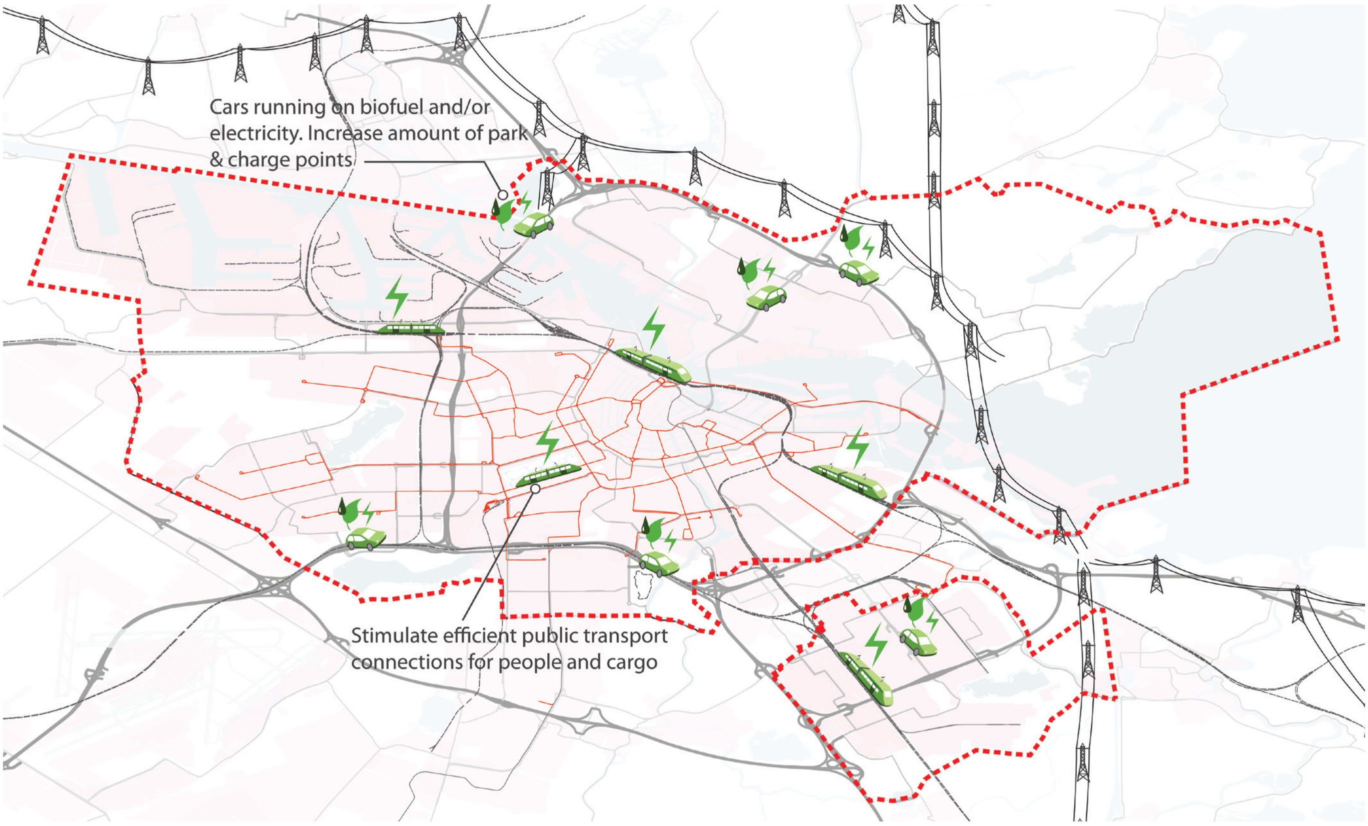


Figure 5.33 Electric public transport for both people and cargo that is well connected through the city reduces the need for cars and trucks. Vehicles still driving can run on biofuel and/or electricity, avoiding disposal of GHG emissions. Biofuel will be the substitute of oil according to Port of Amsterdam (2013).

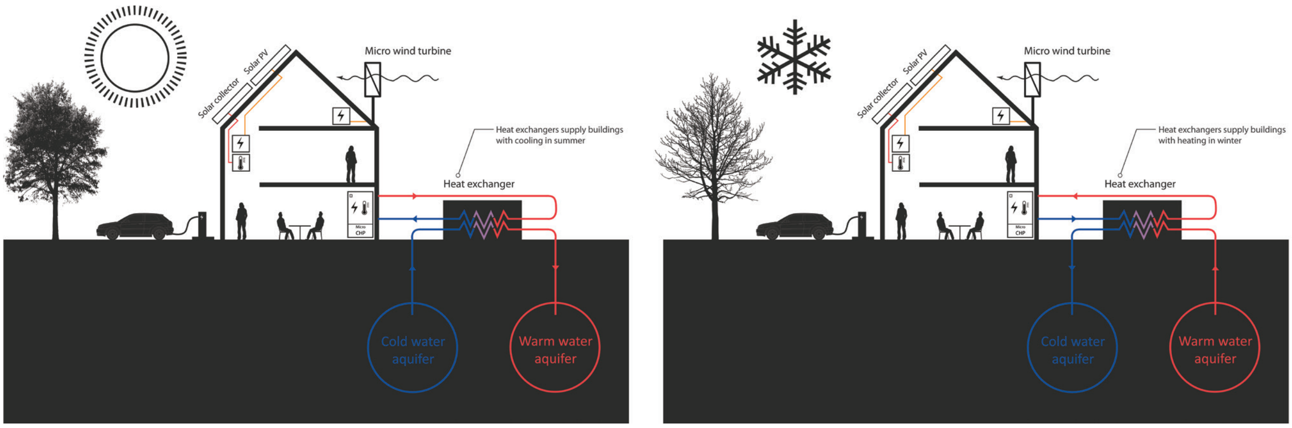


Figure 5.34 Becoming (partly) self-sufficient in energy is possible with various interventions. For cold- and heat storage, cold water is extracted in summer and hot water is extracted in winter.

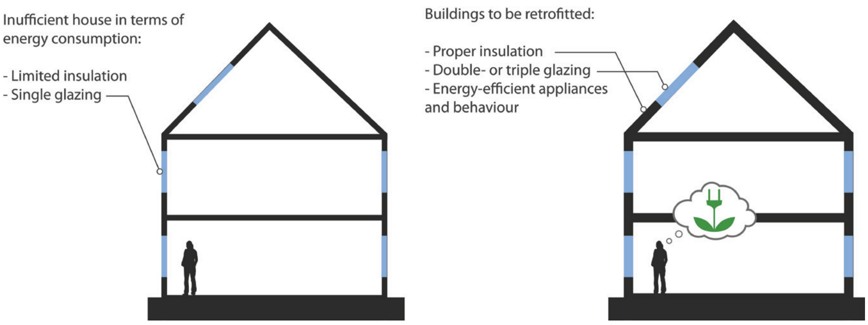


Figure 5.35 Retrofitting of buildings in combination with energy-efficient appliances and behaviour avoid unnecessary energy waste.

7. Discussion and conclusions

7.1 Discussion

During this study, several questions and choices have been made, which have influenced this thesis. These choices and the context will be discussed in this paragraph.

The underlying question of this thesis studying urban metabolism (UM) and sustainable energy landscapes (SEL) researches to us, is whether a city, more specifically its energy systems, can be developed to be sustainable by emulating natural ecosystems, and if possible, what approaches should be taken for sustainable energy systems with the perspective of urban metabolism. During the literature study, it has been answered that the two approaches studied can provide not only descriptive concepts that explain what the world is but also prescriptive insights on how to analyse and interpret, thus achieving sustainable energy systems with optimized-linear urban metabolism. Indeed, urban metabolism and SEL researches are not different but closely related approaches. Concepts from urban metabolism and SES share many things as both studies are based on concepts and metaphors from natural ecosystems. For example, gradual change of UM concept can be also understood by the ecological succession concept of SEL and most of concepts from each approach complements each other. One good example of this is the second law of thermodynamic concept, which is importantly discussed in SEL researches as their basis. Exergy concept has been discussed in the field of industrial ecology, which is the strong tradition of UM studies. Ironically urban metabolism studies tend to lack the importance of exergy concept or at least did not deal with this in their studies 'explicitly'. This can be seen in some of UM papers stating that the urban metabolism concept is relied on the first law of thermodynamics and "the inputs are the sum of outputs and the stock increase" (Newman 1999; Sahely et al. 2003). Moreover, many of UM papers describe linear and circular models of urban metabolism with diagrams, illustrating that the volume or thickness of output line should be highly reduced compared to that of input. However, they have the same amount of energy as energy is always conserved during any spontaneous processes according to the first law of thermodynamics (FLT). While, the qualities of energy in input and output (e.g. exergy) can be drastically decreased through metabolic processes. Therefore, it is desirable to reduce the volume of input and output but their volumes before and after metabolic process should be the same theoretically in UM models since the terms of input and output already imply physical aspects of material and energy. In this sense, further researches on UM should embrace the exergy concept as their basis especially discussing metabolic components of input and output and their implications. Also, urban metabolic strategies to increase energy efficiencies of input, output and internal process in a city should be understood with the idea of increasing exergy of a city itself.

Some suggestions for further researches can be made based on our experience from this thesis. First, one big difficulty that we had during this study was the energy data collection for material flow analysis of Amsterdam's case. This is also mentioned by researchers (e.g.

Barles, 2009). Usually, the amount of imported and assimilated energy can be gathered relatively easily but the amount of energy exported and processed or conversed during the metabolic processes are hard to collect. Thus, we partly had to make assumptions based on what we have already known deductively or refer data that seemed to be generally applicable from other cases. This however more or less decreases the reliability of analysis inevitably. Secondly, urban metabolism with a spatial perspective has only been focussed recently but still tends to have difficulties in providing starting points for end-users such as urban planners and designers, which was one of our knowledge gap. Thus, we studied concepts and strategies with spatial explicit implications for planning and design the energy landscapes in a human built environment. However, MFA, a most frequently used method by researchers, lacks spatial aspects in the analysis and it can also be seen in our sankey diagram visualizing MFA of Amsterdam's energy systems. Different types of analysis such as landscape analysis or energy infrastructure analysis would complement this lack of spatial dimensions in MFA when they are closely combined. Nevertheless, more spatial explicit information in MFA is needed to be used directly by environmental designers since this analysis is considered useful, though one of a multiple methods in quantifying and analyzing cities' material- and energy balances. The method for the case study seems able to define energy-conscious strategies for a city to reach an optimized linear metabolism. These strategies applied for Amsterdam however are still to be investigated and further designed for plans that constitute a renewable energy transition. Because of limited time in this study, it is still unknown which interventions really deserve consideration in master plans, whereas this study reveals a range of varied possibilities for a renewable energy transition.

7.2 Conclusions

In the conclusions essential findings of this study are summarized, in order to give answers to the research questions. Subsequently this study is being put in a global perspective, examining how it can contribute in improving a city's urban (energy) metabolism.

7.2.1 Sub research questions

The main research question was divided into sub research questions. Sub research questions formed support of the research in a procedural way, together being able to answer the main question.

1. Which concepts and strategies for sustainable urban (energy) metabolism are described in the literature with spatial relevance?

Concepts and strategies for sustainable urban energy metabolism are described in chapter 4. Chapter 2 provides a theoretical basis, helping to understand chapter 4. It seemed that energy-conscious strategies and urban metabolism are strongly related with each other. Relating these two fields with a spatial perspective was only conducted recently by a few researches. For example revealing this relation was performed briefly by Leduc and Van Kann (2013), and more extended with spatial prescriptions by Tillie et al. (2014) and Sijmons et al. (2014). This study aimed to reveal this relation explicitly, in order to develop knowledge for end-users on how an optimized linear metabolism can be achieved (Kennedy et al., 2011; Chrysoulakis et al., 2013).

Urban metabolism is in this study divided by the three components input, output and internal processes of ecosystems. This division was based on the question what urban metabolism exists of, inspired from many researches (Chapter 4). A city's urban metabolism is considered to become more sustainable when less input in the form of resources is needed, less output in the form of wastes are disposed, and more efficient internal processes would occur compared with the current situation. Energy-conscious strategies in this report gained relevance for improving input, output and internal processes (Table 4.4). It possible to identify strategies from identified concepts and strategies as conclusions in Chapter 4.

2. How does the current urban (energy) metabolism of Amsterdam work and how can it be represented?

Amsterdam's energy metabolism was analysed in order to illustrate how energy-conscious strategies could improve a city's energy metabolism in practice by identifying inefficiencies and potentials. Chapter 5 shows the analysis of Amsterdam's energy metabolism. Representation of the analysis exists of a land-use inventory including energy infrastructure, a Sankey diagram, and a district analysis of energy consumption and renewable energy potentials. Amsterdam currently relies for the most part on coal and natural gas for energy generation. The city does have various renewable energy sources in function including newer technologies such as district heating, but the proportion of energy generation is little compared to fossil fuel based energy. Conversion losses in power plants and the fossil fuel based transportation sector constitute a significant amount of waste energy compared to the amount of used energy. Amsterdam however has theoretical potential in becoming self-sufficient with assimilation of renewable energy and re-using energy, minimizing GHG emissions and conversion losses. If this potential is able to be fully exploited by investments in time and money remains the question. Ambitions to reduce CO_2 emissions, increase renewable energy, reduce energy consumption, and making transhipment transitions in the port (e.g. from coal to biomass, from oil to biofuel) indicate that the desire for a sustainable Amsterdam is there.

3. Which strategies for sustainable urban (energy) metabolism can be applied to Amsterdam's case?

The specific strategies applied to Amsterdam are selected from the generic strategies concluded in Chapter 4, whereas they are given a context by means of the case study. They are indicative, meaning they can be interpreted and used flexibly. The strategies are defined with three overall terms: renewable energy assimilation, energy flows and energy consumption. Chapter 4 and 5 were essential input for defining the strategies.

7.2.2 Main research question

Which concepts and strategies for sustainable urban (energy) metabolism have been described in the literature and which ones are applicable to the transformation of the urban metabolism in the city of Amsterdam on a spatial way?

Basically this research question is answered in three steps: chapter 4, 5 and 6. As mentioned in chapter 4, there are numerous possibilities in optimizing an urban energy metabolism with energy-conscious strategies. It depends on the particular city which strategies are suitable to be applied. An analysis of the city's urban energy metabolism is therefore required. With identified insufficiencies and potentials, appropriate strategies can be selected. When illustrated, they can form the link to spatial planning and design for end-users such as urban planners and landscape architects.

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Appendix 1 Caloric values

Primary coals	variable
anthracite	29.3 TJ/mln kg
coking coal	28.6 TJ/mln kg
steam coal	variable between 23.5 and 25.2 TJ/mln kg, in 2010: 24.8 TJ/mln kg
brown coal	20.0 TJ/mln kg
Coke oven coke	28.5 TJ/mln kg
Coke oven gas	31.65 TJ/mln m3 ae
Blast furnace gas	31.65 TJ/mln m3 ae
Coal tar	41.9 TJ/mln kg
Crude oil	42.7 TJ/mln kg
Natural gas liquids	44.0 TJ/mln kg
Other hydrocarbons	44.0 TJ/mln kg
Refinery gas	45.2 TJ/mln kg
Chemical waste gas	45.2 TJ/mln kg
LPG (incl. propane and butane)	45.2 TJ/mln kg
Naphtha	44.0 TJ/mln kg
Crude oil aromatics	44.0 TJ/mln kg
Other light oils	44.0 TJ/mln kg
Motor gasoline	44.0 TJ/mln kg
Aviation gasoline	44.0 TJ/mln kg
Kerosene type jet fuel	43.5 TJ/mln kg
Other kerosene	43.1 TJ/mln kg
Heating and other gasoil	42.7 TJ/mln kg
Heavy fuel oil	41.0 TJ/mln kg
Lubricants	41.4 TJ/mln kg
Bitumen	41.9 TJ/mln kg
Other petroleum products	variable
Natural gas	31.65 TJ/mln m3
Electricity	3.6 TJ/mln kWh
Biogas	31.65 TJ/mln m3 ae

Source: http://www.cbs.nl/en-GB/menu/methoden/toelichtingen/alfabet/c/verbrandingswaarden.htm

Appendix 2 Datasheet Sankey Diagram

Datasheet Sankey diagram
28-12-2014
Tom van Heeswijk
Changsoon Choi

System boundary: Municipality Amsterdam
Units: Terajoule [TJ]

A) Import energy	B) Energy generation sources	C) Total energy supply	D) Energy consumption sectors	E) Used energy	F) Waste energy	G) Export energy
Heat		Heat	**Household**	**Used energy**	**Waste energy**	Export electricity
675,86		2.001,26	18.010,09	36.274,70	52.409,89	3.645,92
			13.960,07 G		35.899,54 EG	
			3.382,93 E		7.441,67 T	
			667,09 H		3.602,02 H	
			3.602,02 W		4.134,14 U	
Electricity	Biomass	Electricity generation	**Utility**		1.329,12 I	Export coal
223,04	1.058,50 H	19.449,50	20.670,69		3,40 A	31.937,00
			9.068,48 G			
			10.934,52 E			Storage coal
			667,09 H			490.189,00
			0,60 F			
			4.134,14 W			
Natural gas	Solar thermal	Natural gas supply	**Industry**			
32.914,26	29,3 H	27.537,94	6.645,61			
			4.494,60 G			
			1.483,92 E			
			667,09 H			
			1.329,12 W			
Oil and refined products	Waste		**Agriculture**			Export oil and refined products
848.859,00	2.450,60		17,00			946.864,50
	237,60 H		14,79 G			
	2.213,00 E		2,21 E			
			3,40 W			
Coal	Biogas		**Transportation**			
522.126,00	157,4 E		12.002,70			
			12.002,70 V			
	Solar PV		7.441,67 W			
	23 E					
	Wind onshore					
	476,3 E					
	Electricity for power plants E					
	223,04					
	Natural gas for power plants G					
	5.376,32					
	Coal for power plants C					
	46.880,00					
+	+	+	+			
1.404.122,30	56.674,46	48.988,70	57.346,08			982.447,42

Total electricity renewables
2869,7

Total gas and coal input
52.256,32

Total input electricity production
55.349,06

Total electricity consumption
15.803,58

Total gas consumption
27.537,94

Total heat consumption
1.325,40

Total fuel consumption
12.003,30

EG = electricity generation in power plants
T = transportation sector
H = household sector
U = utility sector
I = industry sector
A = agriculture sector

Gas	G
Electricity	E
Heat	H
Domestic Fuel oil	F
Various fuels: diesel, petrol, LPG and electricity	V
Waste energy	W

Appendix 2.1 Datasheet section A

A) Import energy

A1 Heat (2012)				
Total heat consumption incl. gas	29.539,20			*measured by Klimaatmonitor*
Gas consumption	27.537,94			*measured by Klimaatmonitor*
Heat by local renewables	1.325,40		-	*measured by Klimaatmonitor*
Import heat (Diemen power plant)	**675,86**	TJ		*calculated assumption*

Amsterdam gains residual heat from the Diemen power plant just outside the municipality border, transferred by a district heating network. This assumed heat import is calculated by withdrawing 'gas consumption' and 'heat by local renewables' from 'total heat consumption incl. gas'

A2 Electricity (2012)			
Electricity consumption for energy generation in Municipality Amsterdam	**223,04**	TJ	*measured by Klimaatmonitor*

Considering power plants need immediate electricity for energy generating, it is assumed that this needed electricity amount is extracted from powerlines within the municipality border connected with powerlines outside the municipality border

A3 Natural gas (2012)				
Gas consumption for energy generation in Municipality Amsterdam	5.376,32			*measured by Klimaatmonitor*
Gas consumption by other sectors:				
[1] Household	13.960,07			*measured by Klimaatmonitor*
[2] Utility	9.068,48			*measured by Klimaatmonitor*
[3] Industry	4.494,60			*measured by Klimaatmonitor*
[4] Transportation				
[5] Agriculture	14,79		+	*measured by Klimaatmonitor*
	32.914,26	TJ		*calculated import assumption*

Considering Amsterdam has no self-supply in gas, it is assumed all consumed natural gas is imported

A4 Fuels: diesel, petrol, LPG, fuel oil (2012)					
Total import oil and refined products (tons)	19.514.846				*measured by Port of Amsterdam*
	848.859	TJ			*calculated from CBS 'caloric values' further elaboration on conversion is showed in section **G-3***
Consumption numbers (section D)					
[2] Utility					
Sewage water treatment plants	0,6			domestic fuel oil	*measured by Klimaatmonitor*
[4] Transportation					
Road traffic	7.829,40			diesel, petrol, LPG	*measured by Klimaatmonitor*
Railway traffic	556,7			diesel, electricity (amount of electricity not specified)	*measured by Klimaatmonitor*
Mobile means	1.177			diesel, petrol, LPG	*measured by Klimaatmonitor*
Inland- and recreation shipping	757,1			diesel, petrol	*measured by Klimaatmonitor*
Sea transport and fishing	1.682,50		+	diesel, fuel oil	*measured by Klimaatmonitor*
	12.003,30	TJ			*calculated import assumption*

All consumed fuels are considered to be imported via the port of Amsterdam. Specific amounts of types of fuels are not measured by Klimaatmonitor.

A5 Coal (2012)			
Import of coal (tons)	17.820.000		*measured by Port of Amsterdam* (2012)
	522.126,00	TJ	*converted according to CBS 'Caloric values': 29,3 TJ/mln kg*
Export of coal (tons)	1.090.000		*measured by Port of Amsterdam* (2012)
	31.937	TJ	
Storage of coal (tons)	16.730.000		*calculated from import - export*
	490.189	TJ	

Appendix 2.2 Datasheet section B

B) Local electricity generation sources [TJ]

	Heat	Electricity	Gas	Coal	
Yield (2012)					
Biomass					
Heat from bio energy	987,2				*measured by Klimaatmonitor*
Wood kettles from companies	55,2				*measured by Klimaatmonitor*
Wood kettles from dwellings	15,8				*measured by Klimaatmonitor*
Heat from fresh milk	0,3 +				*measured by Klimaatmonitor*
	1.058,50				*calculated sum*
Solar thermal	29,3				*measured by Klimaatmonitor*
Waste	237,6	2.213			*measured by Klimaatmonitor*
Biogas					
Waste water treatment plants		60,5			*measured by Klimaatmonitor*
Additional biogas		96,9 +			*measured by Klimaatmonitor*
		157,4			*measured by Klimaatmonitor*
Solar PV		23			*measured by Klimaatmonitor*
Wind onshore		476,3			*measured by Klimaatmonitor*
Input (2012)					
Imported electricity for power plants		223,04			*measured by Klimaatmonitor*
Natural gas for power plants			5.376,32		*measured by Klimaatmonitor*
Coal for power plants				46.880,00	*written by Nuon: coal supply for Amsterdam powerplant (Hemweg 8) = 1.600.000 ton coal per year The type of coal is assumed to be anthracite, which brings 29,3 TJ/mln kg ('Caloric values', CBS)
Total heat from local renewables	1.325,40 TJ				
Total electricity from local renewables		2.869,70 TJ			
Total electricity input for power plants		223,04 TJ			
Total gas and coal input			52.256,32 TJ		

Appendix 2.3 Datasheet section C

C1 Heat (2012)			
Total heat consumption incl. gas (2012)	29.539,20		*measured by Klimaatmonitor*
Gas consumption (2012)	27.537,94		*measured by Klimaatmonitor*
Heat by local renewables (2012)	1.325,40	-	*measured by Klimaatmonitor*
Import heat (Diemen power plant)	675,86	TJ	*calculated assumption*
Renewable heat, local			
Biomass	1.058,50		*measured by Klimaatmonitor*
Solar thermal	29,3		*measured by Klimaatmonitor*
Waste	237,6	+	*measured by Klimaatmonitor*
Total renewable heat	**2.001,26**		*calculated total heat*

	C2 Electricity generation (2012)			
v1_20-11-'14	Energy yield STEG- and coal power plants	0,00		*calculated: see description below*
	Total electricity renewables	2.869,70	+	*measured by Klimaatmonitor*
		2.869,70		

Energy yield of Dutch STEG (steam and gas) powerplants is on average 58% (ECN, 2007)
Energy yield of the Amsterdam Hemweg 8 (coal) power plant is 40% (CE Delft, 2011)
The average energy yield of both STEG- and coal power plants together is assumed to be (58+40)/2 = ***49%***
*The total gas- and coal input is 52.256,32 TJ. The assumed energy yield of the power plants then would be (52.256,32/100)*49 = 25.605,60 TJ*
Specific electricity generation from the Nuon power plants was not available

v2_20-12-'14 *After doing the assumption above (20-11-14), access to power plant data in Amsterdam became available, after requesting a meeting with Nuon. This meeting took place on 12-12'14.*
Thus, the measured electricity generation rate became known. Numbers were given from the years 2010-2014. The total number of 2012 is taken, because most data considered in this sheet is also from 2012, giving more reliable comparison of electricity generation- and consumption.

The electricity generation rate from 2012 is:	4.605.494	MWh
This number represents Nuon's power plants located in Municipality Amsterdam	**16.579,8**	TJ

Additional electricity from renewables (2012)			
Waste	2.213,00		*measured by Klimaatmonitor*
Biogas	157,4		*measured by Klimaatmonitor*
Solar pv	23		*measured by Klimaatmonitor*
Wind onshore	476,3	+	*measured by Klimaatmonitor*
Total renewables	2.869,70		
Total electricity generation	**19.449,50**	TJ	

C3 Natural gas supply (2012)			
[1] Household gas consumption	13.960,07		*measured by Klimaatmonitor*
[2] Utility gas consumption	9.068,48		*measured by Klimaatmonitor*
[3] Industry gas consumption	4.494,60		*measured by Klimaatmonitor*
[4] Agriculture gas consumption	14,79	+	*measured by Klimaatmonitor*
	27.537,94	TJ	

The gas supply for sectors excluding power plants is based on the gas consumption of these sectors.
In total this number is calculated to be 27.537,94 TJ

Appendix 2.4 Datasheet section D: Household

D) Energy consumption sectors + E) Used energy

m3 gas	1.000.000	31,48 TJ
kWh	277.777.778	1 TJ
kWh	1	0,0000036 TJ

Consumption sectors 1, 2, 3, 4, 5 Amsterdam (total consumption/year)

Source: Klimaatmonitor databank

[1] Household averages per unit (2012)

	Gas m3	Electricity kWh
Apartments (appartement)	987,00	2.150,00
Town houses (tussenwoning)	1.135,00	2.750,00
Corner houses (hoekwoning)	1.431,00	3.200,00
Semi-detached (2-onder-1-kap)	1.776,00	3.750,00
Detached (vrijstaand)	2.516,00	4.600,00
Additional/unknown (2010)	1.183,00	2.400,00

[1] Household consumption, total (2012)

Gas m3	414.274.988,00	13.960,07 TJ	17.343,00 TJ Gas & electricity
Electricity kWh	939.703.900,00	3.382,93 TJ	

Total [1] Household	**17.343,00 TJ**

Appendix 2.5 Datasheet section D: Utility

[2] Utility (Klimaatmonitor, 2012)

2.1 Commercial service (2012)	Gas m3	Electricity kWh	
Wholesale, retail and car repair	32.327.000	386.136.992	
Transport and storage	24.081.000	383.444.000	
Hotel & catering industry	44.176.000	311.688.992	
Information & communication	14.291.000	691.208.000	
Financial- & insurance industry	19.323.000	230.656.992	
Trade and real estate	25.165.000	164.123.008	
Scientific and technical activities	9.999.000	88.446.000	
Administrative and supportive service	6.085.000	83.897.000	
		+	
Total, orginial value	175.447.000	2.339.600.984	
TJ	4.656,74	8.422,56	13.079,30 TJ Gas & electricity

Grey = data from 2011

2.2 Public service (2012)	Gas m3	Electricity kWh	
Public management & defence	22.940.000	160.771.008	
Education	28.134.000	109.094.000	
Health care	63.525.000	248.248.000	
Recreation, art, entertainment	15.714.000	117.119.000	
Extra-territorial organizations	119.000	323.000	
Additional service	8.610.000	30.706.000	
Rijkswaterstaat			
Bridges and dams		9.940	
Offices		507.991	
Small buildings		0	
Measuring stations		372	
Public lighting		2.227.623	
Radar posts		34.850	
Sluices and dams		1.085.862	
Tunnels		1.284.986	
Traffic stations		0	
Lighthouses		1.392	
Additional		0	
Total Rijkswaterstaat		*5.153.016*	
		+	
Total, original value	139.042.000	671.414.024	
TJ	4.377,21	2.417,09	6.794,30 TJ Gas & electricity

2.3 Sewage water treatment plants (2012)				
Domestic fuel oil liters	11.692	0,6	TJ	
Gas m3	1.097.901	34,53	TJ	
Electricity kWh	26.351.527	94,87	TJ	
		+		
	Total	130	TJ	130 TJ Gas, electricity and domestic fuel oil

Total [2] Utility	**20.003,60 TJ**

Appendix 2.6 Datasheet section D: Industry

[3] Industry (Klimaatmonitor, 2012)

3.1 Industry (2012)				
Gas m3	13.154.500	4.163,36	TJ	
Electricity kWh	315.455.008	1.135,64	TJ	
		+		
		5.299,00		5.299,00 TJ Gas & electricity

3.2 Construction industry (2012)				
Gas m3	3.926.000	124,25	TJ	
Electricity kWh	20.904.000	75,25	TJ	
		+		
		199,5		199,5 TJ Gas & electricity

3.3 Excavation of minerals				
Gas m3 (2010)	1.941.000	61,12	TJ	
Electricity kWh (2012)	21.694.000	78,1	TJ	
		+		
		139,22		139,22 TJ Gas & electricity

3.4 Waste processing (2012)				
Gas m3	4.609.616	145,87	TJ	
Electricity kWh	54.147.342	194,93	TJ	340,8 TJ Gas & electricity

Total [3] Industry	**5.978,52 TJ**

Appendix 2.7 Datasheet section D: Transportation and Agriculture

[4] Transportation (Klimaatmonitor, 2012)

4.1 Road traffic: highways and other roads (2012)				
Diesel, petrol and LPG		7.829,40	TJ	7.829,40 TJ Diesel, petrol, LPG
4.2 Railway traffic (2012)				
Diesel and electricity		556,7	TJ	556,7 TJ Diesel & electricity
4.3 Mobile means (2012)				
Diesel, petrol and LPG		1.177	TJ	1.177 TJ Diesel, petrol, LPG
4.4 Inland- and recreation shipping (2012)				
Diesel and petrol		757,1	TJ	757,1 TJ Diesel & petrol
4.5 Sea transport and fishing (2012)				
Diesel and fuel oil		1.682,50	TJ	1.682,50 TJ Diesel & fuel oil
Total [4] Transportation	**12.002,70 TJ**			

[5] Agriculture (Klimaatmonitor, 2012)

5. Agriculture (2012)				
Gas m3	467.000	14,79	TJ	
Electricity kWh	613.000	2,21	TJ	
		+		
		17	TJ	17 TJ Gas & electricity
Total [5] Agriculture	**17 TJ**			

Appendix 2.8 Datasheet section E

Total gas consumption	27.537,94	TJ		*measured by Klimaatmonitor*
Total electricity consumption	15.803,58	TJ		*measured by Klimaatmonitor*
Total fuel consumption	12.003,30	TJ		*measured by Klimaatmonitor*
			+	
Total consumption gas+elec.+fuels	55.344,82	TJ		*measured by Klimaatmonitor*
Total heat consumption incl. gas (2012)	29.539,20			*measured by Klimaatmonitor*
Gas consumption	27.537,94			*measured by Klimaatmonitor*
Heat by local renewables	1.325,40		-	*measured by Klimaatmonitor*
Import heat (Diemen power plant)	675,86	TJ		*calculated assumption*
Heat by local renewables	1.325,40			*measured by Klimaatmonitor*
Imported heat	675,86		+	*calculated assumption*
Total renewable heat consumption*	2.001,26			*calculated assumption*

** Derived from the existing heat network it is assumed that the total amount of renewable heat is equally distributed among sectors [1] Household, [2] Utility and [3] Industry.*

The assumed distribution is then 2.001,26/ 3 =

667,09 TJ per sector

Total consumption gas+elec.+fuels+ renewable heat	**57.346,08**	TJ

Appendix 2.9 Datasheet section F

F) Waste energy

v1_20-11-'14 *Amount of waste energy is based on the energy conversion process of STEG- and coal power plants in Municipality Amsterdam.*
Energy yield of Dutch STEG (steam and gas) powerplants is on average 58% (ECN, 2007)
Energy yield of the Amsterdam Hemweg 8 (coal) power plant is 40% (CE Delft, 2011)
The average energy yield of both STEG- and coal power plants together is assumed to be (58+40)/2 = 49%
*A remaining **51%** of the total gas- and coal input occurs then as waste energy*

The total gas- and coal input of power plants in Amsterdam is 52.256,32 TJ
*The amount of waste energy is then (52.256,32/100)*51 =* **26.650,72** TJ

v2_20-12-'14 When Nuon gave access to their power plant data (12-12-'14), specific electricity generation and therefore a more specific amount of waste energy became available. The waste energy or conversion loss applies for electricity generation from gas and coals (the power plants in Amsterdam).
This assumed amount exists of: input electricity, gas and coals - electricity generation from power plants.
The electricity generation implies electricity from power plants and renewable energy sources.
Input of electricity is 223,04 TJ. Input gas and coals is 52.256,3 TJ. Actual electricity generation from power plants is 16.579,8 TJ.
Thus the assumed 'waste energy' or also known as 'conversion loss' =
(52.256,3 + 223,04) - 16.579,8 = **35.899,5** TJ

A second sector that contains a large conversion loss is sector D) Transportation.
The largest part of the used fuels consist of fossil fuels such as diesel, petrol and LPG.
Only a small share of electricity is used as a fuel in Railway traffic (sector D, section 4.2).
Because the exact number of this electricity use is unknown, the total transportation energy consumption of 12.002,7 TJ is considered to exist of fossil fuels.
Average energy losses in internal combustion engines of vehicles would be 62%.
Source: http://www.consumerenergycenter.org/transportation/consumer_tips/vehicle_energy_losses.html
Due to time limitations of this study, more specific numbers for energy loss in cars as well as ships and railway transport were not found yet.
Considering the 62% energy loss from a total transport consumption of 12.002,7 TJ,
the conversion loss = 12.002,7 * 0,62 = **7.441,7** TJ

The other sectors also have waste energy. For example electricity and gas can be used unnecessarily or inefficiently in households, utility and industry. Another example is remaining energy in the form of residual heat that is often disposed.
Specific numbers about this waste energy were not available, but an assumption for this inefficient use of energy is based on the book 'Landscape and Energy' from Dirk Sijmons (2014).
Sankey diagrams in this book holds waste energy streams of households, utility, industry and agriculture as approximately 20% of the energy consumption of these sectors.

Sector	*Consumption*	*Waste factor*	*Waste energy*	
Households	18.010,09	0,2	3.602,0	TJ
Utility	20.670,69	0,2	4.134,1	TJ
Industry	6.645,61	0,2	1.329,1	TJ
Agriculture	17,00	0,2	3,4	TJ

Total waste energy from Households, Utility, Industry and Agriculture = **9.068,7** TJ

Total amount of waste energy/conversion loss is then: **52.409,9** TJ

Appendix 2.10 Datasheet section G

G) Export energy

G1 Export electricity (2012)

Export of electricity towards areas outside the border of Municipality Amsterdam is based on the amount of locally consumed electricity withdrawed from the total electricity generation in Amsterdam: electricity generation minus electricity consumption

Electricity generation		Electricity consumption			
19.449,50	-	15.803,58	=	**3.645,92**	TJ

G2 Export coal (2012)

Import of coal (tons)	17.820.000		*measured by Port of Amsterdam* (2012)
	522.126	TJ	*converted according to CBS 'Caloric values': 29,3 TJ/mln kg*
Export of coal (tons)	1.090.000		*measured by Port of Amsterdam* (2012)
	31.937	TJ	*converted according to CBS 'Caloric values': 29,3 TJ/mln kg*
		-	
Storage of coal (tons)	16.730.000		*calculated from import - export*
	490.189	TJ	*converted according to CBS 'Caloric values': 29,3 TJ/mln kg*

G3 Export oil and refined products (2012)

Import (tons)	19.514.846		*measured by Port of Amsterdam* (2012)
	848.859	TJ	*calculated from CBS 'caloric values'. Further elaboration below*
Export (tons)	21.767.102		*measured by Port of Amsterdam* (2012)
	946.865	TJ	*calculated from CBS 'caloric values'. Further elaboration below*

Because 'oil and refined products' is a broad term (term used by Port of Amsterdam), oil-based fuels mentioned in 'caloric values' of CBS are accumulated in terms of their caloric values (TJ/mln kg), and subsequently divided by 11 (amount of fuel types).
The outcoming number then represents the average caloric value of 'oil and refined products': 43,5

CBS caloric values	TJ/mln kg
crude oil	41,9
LPG	45,2
crude oil aromatics	44
other light oils	44
motor gasoline	44
aviation gasoline	44
kerosene jet fuel	44
other kerosene	43,5
heavy fuel oil	42,7
heating- and other gasoil	43,1
other petroleum products	41,9
Average caloric value oil and refined products	43,5

Appendix 3 Potentials districts

Potentials per district [TJ]

District	Wind	Solar	Open heat-cold storage*	Waste	Residual heat	Geothermal heat	**Total potential [TJ]**
Amsterdam-Centrum	0	215,65	1.610,16	30,0	3,34	234,53	2.093,7
Amsterdam-Noord	453,6	328	26.159,08	34,5	1,67	211,33	27.188,2
Westpoort	720	162,28	39.721,08	1.134,0	185,48	2.632,13	44.555,0
Zuidoost	558	225,07	9.031,84	32,4	218,90	47,65	10.113,9
Oost-Watergraafsmeer	79,2	133,4	2.956,73	23,0	13,37	541,61	3.747,3
Zeeburg	270	101,95	10.459,67	21,9	0	286,36	11.139,9
Geuzenveld-Slotermeer	0	6,66	2.126,86	17,6	0	1.281,73	3.432,8
Osdorp	0	75	2.263,82	21,4	0	1.543,79	3.904,0
Slotervaart	0	49,78	2.899,18	19,9	40,10	1.455,95	4.464,9
Bos en Lommer	0	20,19	219,82	13,4	1,67	130,44	385,6
Westerpark	0	65,12	454,44	14,8	0	59,29	593,7
De Baarsjes	0	20,7	69,53	14,8	0	149,33	254,3
Oud-West	0	43,67	77,26	14,1	0	171,29	306,3
Oud-Zuid	0	142,28	1.376,43	33,2	0	368,93	1.920,9
Zuider Amstel	0	107,53	2.507,73	18,9	193,84	152,26	2.980,3
[Diemen power plant]					501,3		
Total [TJ]	2.080,8	1.697,3	101.933,6	1.444,0	1.159,7	9.266,6	
Total excl. Diemen [TJ]					658,374		

* Open heat-cold storage: total amount of potential is distributed among 50% cold and 50% heat
This means 50.997 TJ heat and 50.997 TJ cold

Appendix 3.1 Potentials wind, solar and open cold-heat storage

Wind potential GWh/year

Favourable areas for wind turbines are mapped according to PlanMER Windvisie (2012)
These areas are given an estimated capacity and expected energy generation per year, when implementing 7,5 MW and 3 MW wind turbines.
Potentials per district are calculated with ArcGIS.

District	*Capacity MW*	*Expected energy generation GWh*		*Expected energy generation TJ*		
Westpoort	100	200		720	Locatie 1	* Overlaps Geuzenveld-Slotermeer and Bos & Lommer for a small part
Amsterdam-Noord	24	53			Locatie 2	
	15	31			Locatie 3	
	12	42	+		Locatie 4	
	51	126		453,6		
Zeeburg	31,5	75		270	Locatie 5	* Overlaps Oost-Watergraafsmeer for a small part
Oost-Watergraafsmeer	12	22		79,2	Locatie 6	
Zuidoost	48	108			Locatie 7	
	12	27			Locatie 8	
	9	20	+		Locatie 9	
	69	155		558		
Total	263,5	578		2.080,8		

Solar potentials kWh

kWh per district is calculated in ArcGIS from a shapefile received from Laura Hakvoort (DRO Amsterdam)
Roofs of buildings are considered for the potentials: shade, surface of roof and sloping of roof are taken into account

District	*Potential kWh*	*TJ*
Amsterdam-Centrum	59.904.057	215,65
Amsterdam-Noord	91.111.479	328
Westpoort	45.079.054	162,28
Zuidoost	62.518.616	225,07
Oost-Watergraafsmeer	37.060.334	133,4
Zeeburg	28.319.494	101,95
Geuzenveld-Slotermeer	1.849.431	6,66
Osdorp	20.827.552	75
Slotervaart	13.826.845	49,78
Bos en Lommer	5.608.855	20,19
Westerpark	18.088.861	65,12
De Baarsjes	5.750.631	20,7
Oud-West	12.129.954	43,67
Oud-Zuid	39.521.525	142,28
Zuider Amstel	29.869.751	107,53
	471.466.439	1.697,3

Open heat-cold storage potential

Formula: 'Energetic capacity' * 0,65 * 0,50 * built area factor
Based on Energy Atlas (2014)

Single source system efficiency
0,65

Thermal loss factor
0,5

District	*[GIS] Accumulated MJ/1 km2*	*Surface m2*	*Energetic capacity MJ*	Built area factor	Practical capacity MJ	TJ
Zuidoost	1.832.581,4	21.663.655	39.700.411.209	0,70	9.031.843.550	**9.031,84**
Oost-Watergraafsmeer	847.503,1	10.734.631	9.097.633.050	1,00	2.956.730.741	**2.956,73**
Zeeburg	1.623.557,5	19.822.887	32.183.596.861	1,00	10.459.668.980	**10.459,67**
Geuzenveld-Slotermeer	974.652,3	10.329.803	10.067.966.252	0,65	2.126.857.871	**2.126,86**
Osdorp	969.602,6	11.052.274	10.716.313.606	0,65	2.263.821.249	**2.263,82**
Slotervaart	1.019.846,3	11.662.605	11.894.064.558	0,75	2.899.178.236	**2.899,18**
Bos en Lommer	241.170,6	2.804.540	676.372.595	1,00	219.821.093	**219,82**
Westerpark	331.234,3	4.221.446	1.398.287.711	1,00	454.443.506	**454,44**
De Baarsjes	124.476,5	1.718.826	213.953.445	1,00	69.534.869	**69,53**
Oud-West	134.366,7	1.769.207	237.722.506	1,00	77.259.815	**77,26**
Oud-Zuid	590.416,3	7.173.181	4.235.162.985	1,00	1.376.427.970	**1.376,43**
Zuider Amstel	741.789,3	10.401.994	7.716.087.848	1,00	2.507.728.551	**2.507,73**
Amsterdam-Centrum	588.003,0	8.425.728	4.954.353.341	1,00	1.610.164.836	**1.610,16**
Amsterdam-Noord	5.158.023,2	62.418.845	321.957.850.627	0,25	26.159.075.363	**26.159,08**
Westpoort	3.474.477,8	35.176.138	122.218.710.571	1,00	39.721.080.935	**39.721,08**
Total	18.651.700,9	219.375.760	577.268.487.164		101.933.637.566	**101.933,63** TJ

*MJ per km2 is calculated in ArcGIS, with a shapefile received from Laura Hakvoort (DRO Amsterdam)

surface is calculated with AutoCAD

Appendix 3.2 Potential waste part 1

Amounts of kg waste per district are based on an interactive map from www.maps.amsterdam.nl

Domestic waste Amsterdam (kg)

Kilograms are calculated from maps.amsterdam.nl
Energetic formula for waste is based on Energy Atlas (2014)

	Amsterdam-Centrum	Amsterdam-Noord	Zuidoost	Westpoort
Garden waste	2868040	170558	162722	
Fruit and vegetable waste	6801352	1790859	3823967	
Residual waste	12537432	23622283	20014806	
Total	**22.206.824**	**25.583.700**	**24.001.495**	**840.000.000** *
Practical potential GJ	29.979,2	34.538,0	32.402,0	1.134.000
TJ	**29,9792124**	**34,537995**	**32,40201825**	**1134**

* According to Energy Atlas, total industrial waste is 840.000.000 kg This is assumed to come from industrial area Westpoort

Formula for waste:
total kg * 0,50 = ... / 1000 = ... * 10 GJ = ... * 0,27 = ... GJ practical potential

0,5 = suitable percentage for incineration
/ 1000 * 10 GJ = energetic value of 10 GJ per 1000 kg
0,27 = 27% power plant AEB efficiency

Zeeburg — kg **16.255.569**

Residual	Fruit & vegetable	Garden
866125	232375	88725
888060	238260	90972
781.050	209.550	80.010
299095	80245	30639
377405	101255	38661
280440	75240	28728
812415	217965	83223
1211140	324940	124068
373510	100210	38262
557805	149655	57141
521315	139865	53403
654155	175505	67011
485645	130295	49749
93275	25025	9555
50225	13475	5145
64780	17380	6636
479290	128590	49098
174660	46860	17892
1385185	371635	141897
552475	148225	56595
296840	79640	30408
654155	175505	67011
11.859.045	3.181.695	1.214.829

Practical potential GJ
21.945,0

TJ
21,94501815

Oost-Watergraafsmeer — kg **17.060.925**

Residual	Fruit & vegetable	Garden
822870	220770	84294
747635	200585	76587
100.450	26.950	10.290
293150	78650	30030
515165	138215	52773
592655	159005	60711
993840	266640	101808
61295	16455	6279
354240	95040	36288
24600	6600	2520
724880	194480	74256
1067845	286495	109389
405080	108680	41496
492820	132220	50484
633450	169950	64890
719755	193105	73731
628325	168575	64365
46945	12595	4809
822255	220605	84231
302170	81070	30954
166870	44770	17094
175070	46970	17934
367155	98505	37611
229600	61600	23520
134275	36025	13755
124025	33275	12705
538740	144540	55188
361415	96965	37023
12.446.575	3.339.335	1.275.015

Practical potential GJ
23.032,2

TJ
23,032249

De Baarsjes — kg **10.928.640**

total
524160
1002880
582.400
597760
737280
432960
684480
268480
990080
573440
489280
330880
1090880
557760
1158720
907200
10928640

Practical potential GJ
14.753,7

TJ
14,753664

Bos en Lommer — kg **9.948.480**

1254720
599680
1476800
332160
461440
674880
55360
2119680
1804800
1168960
9948480

Practical potential GJ
13.430,4

TJ
13,43045

Westerpark — kg **10.994.880**

321600
380160
987840
1156160
847680
279680
866880
1051520
453760
386880
394560
308160
638720
181760
885120
540800
403520
413120
496960
10994880

Practical potential GJ
14.843,1

TJ
14,843088

Geuzenveld-Slotermeer — kg **13.019.024**

824268
979824
975354
472628
928270
1124354
984592
971778
993234
1789192
77182
1397620
685102
815626
13019024

Practical potential GJ
17.575,7

TJ
17,57568

Osdorp — kg **15.849.828**

1090084
350746
845128
1475100
1484338
806388
866584
970586
2053322
172840
1777570
1364244
1080250
1512648
15849828

Practical potential GJ
21.397,3

TJ
21,39727

Slotervaart — kg **14.748.322**

959262
943170
1093366
845426
605536
749172
1472120
174926
930356
996810
222308
237804
186548
431206
873140
868372
651130
463688
299788
727418
606728
256876
66454
86718
14748322

Practical potential GJ
19.910,2

TJ
19,9102347

Appendix 3.2 Potential waste part 2

		kg
Zuider Amstel		**14.023.273**
Residual	**Fruit & vegetable**	**Garden**
589315	126086	87712
488050	104420	72640
905.150	193.660	134.720
610815	130686	90912
259720	55568	38656
29025	6210	4320
528685	113114	78688
474505	101522	70624
664995	142278	98976
542230	116012	80704
434085	92874	64608
348300	74520	51840
323145	69138	48096
172860	36984	25728
633605	135562	94304
699825	149730	104160
38700	8280	5760
864730	185012	128704
733365	156906	109152
171785	36754	25568
777225	166290	115680
10.290.115	2.201.606	1.531.552

Practical potential GJ
18.931,4

TJ
18,931419

	kg	
Oud-Zuid	**24.615.163**	
Residual	**Fruit & vegetable**	**Garden**
299495	64078	44576
330240	70656	49152
710.360	151.984	105.728
510410	109204	75968
462035	98854	68768
517505	110722	77024
521160	111504	77568
640055	136942	95264
1040600	222640	154880
406780	87032	60544
765830	163852	113984
495360	105984	73728
474290	101476	70592
595550	127420	88640
712725	152490	106080
514710	110124	76608
532555	113942	79264
177590	37996	26432
307450	65780	45760
280575	60030	41760
288100	61640	42880
262730	56212	39104
165120	35328	24576
425270	90988	63296
401405	85822	59744
635110	135884	94528
182965	39146	27232
299495	64078	44576
515140	110216	76672
524600	112240	78080
315835	67574	47008
285950	61180	42560
542445	116058	80736
317555	67942	47264
500950	107180	74560
830330	177652	123584
488480	104512	72704
318200	68080	47360
434945	93058	64736
32465	6946	4832
18.062.365	3.864.446	2.688.352

Practical potential GJ
33.230,5

TJ
33,23047

	kg	
Oud-West	**10.421.120**	
Residual	**Fruit & vegetable**	**Garden**
1007958	255234	121128
502348	127204	60368
695.738	176.174	83.608
420099	106377	50484
668943	169389	80388
483009	122307	58044
581801	147323	69916
576209	145907	69244
518658	131334	62328
1246317	315591	149772
487203	123369	58548
198516	50268	23856
201079	50917	24164
7.587.878	1.921.394	911.848

Practical potential GJ
14.068,5

TJ
14,068512

Appendix 3.3 Potential residual heat and geothermal heat

Residual heat potential

Residual heat is based on Energy Atlas (2014)

To only reveal potentials that make a significant contribution to renewable energy, values of 500 GJ (0,5 TJ) and lower are excluded

GJ to TJ factor: 0,001

Efficiency factor: 0,3342

Formula for practical potential: theoretical ... GJ * 0,3342 = ... GJ

0,3342 = efficiency factor (Energy Atlas, 2014)

	District	*Heat potential GJ*	*Number of units*	*Theoretical heat potential GJ*		*Practical potential GJ*	*Practical potential TJ*	*Source*
	Westpoort	500000	1	500000				AEB power plant
		5000	4	20000				Data centers
		5000	7	35000	+			Offices
				555.000		185481	185,481	
	Slotervaart	50000	1	50000				Datacentre
		50000	1	50000				Power plant
		5000	3	15000				Hospitals
		5000	1	5000	+			Office
				120.000		40104	40,104	
	Amsterdam-Noord	5000	1	**5.000**		1671	1,671	Hospital
	Bos en Lommer	5000	1	**5.000**		1671	1,671	Office
	Amsterdam-Centrum	5000	2	**10.000**		3342	3,342	Offices
	Zuider Amstel	50000	1	50.000				Hospital
		500000	1	500.000				Power plant
		5000	6	30.000	+			Offices
				580.000		193836	193,836	
	Oost-Watergraafsmeer	5000	4	20.000				Data centers
		5000	3	15.000				Offices
		5000	1	5.000	+			Hospital
				40.000		13368	13,368	
	Zuidoost	500000	1	500000				Power plant
		50000	1	50.000				Hospital
		50000	1	50.000				Data center
		5000	6	30.000				Data centers
		5000	5	25.000	+			Offices
				655.000		218901	218,901	
[external]	Diemen 33+34 power plant	500000	3	**1.500.000**		501300	501,3	Power plant
			Total	**3.470.000**	GJ	**1.159.674**	**1.159,7**	

Geothermal heat potential

Conversion PJ to TJ: 1000

Geothermal system efficiency: 73,2% (Energy Atlas, 2014): 0,732

District	*Geothermal potential surface within district km2*	*Average potential PJ/km2*	*Potential PJ*	*Potential TJ*	*Practical potential TJ*	
Westpoort	27,66	0,13	3,5958	3595,8	**2.632,13**	
Amsterdam-Noord*	1,92	0,15	0,28870245	288,70245	**211,33**	* Although Amsterdam-Noord covers a big area, the
Zeeburg	6,52	0,06	0,3912	391,2	**286,36**	surface of geothermal potential was small compared
Westerpark	0,54	0,15	0,081	81	**59,29**	to this amount
Amsterdam-Centrum	2,67	0,12	0,3204	320,4	**234,53**	
Bos en Lommer	1,98	0,09	0,1782	178,2	**130,44**	
Oost-Watergraafsmeer	10,57	0,07	0,7399	739,9	**541,61**	
De Baarsjes	1,7	0,12	0,204	204	**149,33**	
Oud-West	1,8	0,13	0,234	234	**171,29**	
Geuzenveld-Slotermeer	10,3	0,17	1,751	1751	**1.281,73**	
Osdorp	11,1	0,19	2,109	2109	**1.543,79**	
Slotervaart	11,7	0,17	1,989	1989	**1.455,95**	
Oud-Zuid	7,2	0,07	0,504	504	**368,93**	
Zuider Amstel	10,4	0,02	0,208	208	**152,26**	
Zuidoost	21,7	0,003	0,0651	65,1	**47,65**	+
				12.659	**9.266,61**	

Appendix 4. Energy consumption for transport, districts

Energy consumption for transportation

Unlike energy consumption for households and utility, the energy consumption for the transportation sector is not measured in the CO2-uitstoot rapportage 2009.
Thus the numbers representing 2009 are still missing accurately measured numbers considering transportation in the 15 districts. To offer an indication of the energy consumption per district considering transport, the estimated energy consumption per capita for transport is used.
For the total energy consumption of transport, numbers from 2012 are used for a recent indication.

The energy consumption per capita = total energy consumption transport / amount of Amsterdam inhabitants.

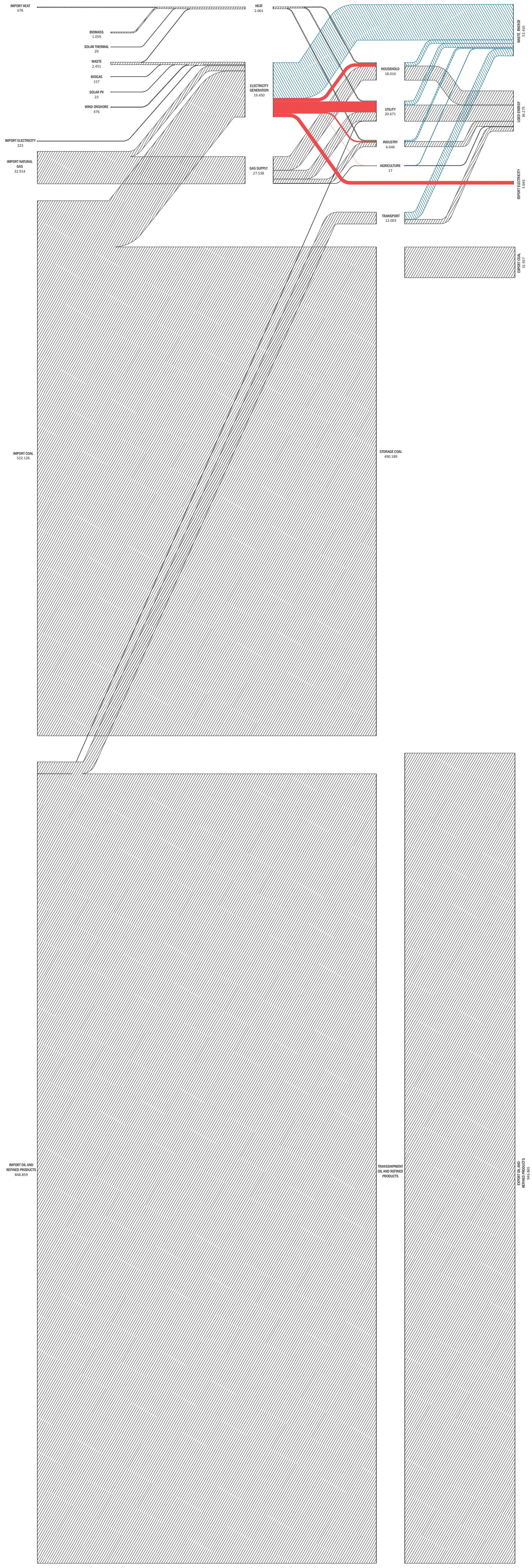
Total energy consumption transport:	12.002,7	TJ	*measured by Klimaatmonitor, 2012*
Amount of Amsterdam inhabitants:	810.937		*measured by CBS, 12 dec. 2014*
Transport energy consumption per capita =	**0,01480103**	TJ	*calculated*

Subsequently, the energy consumption per capita is multiplied with the amount of inhabitants per district. Then, an indication of the energy consumption for transport per district can be given.
The 15 districts are an old configuration of Amsterdam districts, and used in the CO2-uitstoot rapportage 2009.
(since the 1st of May 2010 Amsterdam has administrative borders of 8 simplified districts)
The following amounts of inhabitants in these former districts are derived from Wikipedia, Wikipedia subsequently derived these numbers from CBS (Centraal Bureau Statistiek).

District	Inhabitants	Year	Energy consumption transport [TJ]
Bos en Lommer	30.660	2003	**453,8**
Oud-West	31.741	2003	**469,8**
De Baarsjes	33.847	2007	**501,0**
Westerpark	34.059	2007	**504,1**
Oud-Zuid	83.696	2005	**1.238,8**
Zuider Amstel	46.784	2007	**692,5**
Amsterdam-Centrum	81.110	2009	**1.200,5**
Oost-Watergraafsmeer	57.666	2003	**853,5**
Zeeburg	52.701	2009	**780,0**
Zuidoost	84.811	2003	**1.255,3**
Amsterdam-Noord	86.675	2011	**1.282,9**
Westpoort	370	2007	**5,5**
Geuzenveld-Slotermeer	40.605	2003	**601,0**
Osdorp	45.627	2006	**675,3**
Slotervaart	44.006	2006	**651,3**
			+
	754.358		11.165,3 *

* This total number of consumption in TJ is smaller than the total of 12.002,7 measured in 2012, due to differences in years of measurement. However, the 11.165,3 is considered to be still an accurate indication of energy consumption for transport.

Appendix 5. Current energy balance



Appendix 6. Energy consumption per district specified

Consumption per district (2009)

Source: CO2-uitstoot rapportage 2009 (publication: 2011)

District	Households *Electricity GWh*	Companies *Electricity GWh*	Total GWh	**TJ**	Households Gas x million m3	Companies Gas x million m3	Total million m3	**TJ**	Transportation [TJ]	**Total consumption [TJ]**	Inhabitants	Consumption per capita [TJ]	[GJ]
Amsterdam-Centrum	293	346	639	**2.300,4**	96	22	118	**3.714,64**	**1.200,5**	**7.215,6**	81.110	0,09	89,0
Amsterdam-Noord	151	133	284	**1.022,4**	55	13	68	**2.140,64**	**1.282,9**	**4.445,9**	86.675	0,05	51,3
Westpoort	22	604	626	**2.253,6**	7	36	43	**1.353,64**	**5,5**	**3.612,7**	370	9,76	9.764,1
Zuidoost	134	385	519	**1.868,4**	36	23	59	**1.857,32**	**1.255,3**	**4.981,0**	84.811	0,06	58,7
Oost-Watergraafsmeer	103	185	288	**1.036,8**	41	25	66	**2.077,68**	**853,5**	**3.968,0**	57.666	0,07	68,8
Zeeburg	99	38	137	**493,2**	19	1	20	**629,60**	**780,0**	**1.902,8**	52.701	0,04	36,1
Geuzenveld-Slotermeer	58	17	75	**270,0**	23	0	23	**724,04**	**601,0**	**1.595,0**	40.605	0,04	39,3
Osdorp	84	19	103	**370,8**	24	5	29	**912,92**	**675,3**	**1.959,0**	45.627	0,04	42,9
Slotervaart	71	232	303	**1.090,8**	24	16	40	**1.259,20**	**651,3**	**3.001,3**	44.006	0,07	68,2
Bos en Lommer	42	23	65	**234,0**	18	1	19	**598,12**	**453,8**	**1.285,9**	30.660	0,04	41,9
Westerpark	59	46	105	**378,0**	22	2	24	**755,52**	**504,1**	**1.637,6**	34.059	0,05	48,1
De Baarsjes	55	0	55	**198,0**	23	0	23	**724,04**	**501,0**	**1.423,0**	33.847	0,04	42,0
Oud-West	70	15	85	**306,0**	27	1	28	**881,44**	**469,8**	**1.657,2**	31.741	0,05	52,2
Oud-Zuid	205	90	295	**1.062,0**	80	6	86	**2.707,28**	**1.238,8**	**5.008,1**	83.696	0,06	59,8
Zuider Amstel	99	207	306	**1.101,6**	34	40	74	**2.329,52**	**692,5**	**4.123,6**	46.784	0,09	88,1
Subtotal	1.545	2.340	3885	**13.986**	529	191		**22.665,60**			754.358		
Additional consumption*	-	437		1.573,20	-	132		4155,36					
Total	1.545	2.777	4.322	**15.559,2**	529	323	852	**26.820,96**	**11.165,3**	**47.816,9** TJ excl. Additional consumption*			
										53.545,43 TJ incl. additional consumption			

* Additional consumption: some consumption is directly linked to a company.
For privacy reasons these numbers are not available in public for specific districts.

Appendix 6. Three urban metabolic components and their elements

	Input	**Internal processes**	**Output**
Zhang and Yang, 2007	Material input	- Material conversion - Material storage	Waste discharge
Hau and Bakshi, 2004.	solar energy, geothermal heat and tidal energy		
	Material inflow	Material stock/storage	Material outflow
Newman (1999)	Resource inputs (Land, Water, Food, Energy, Building material and Other resources)		Waste outputs (Solid waste, Liquid waste, Toxics, Sewage, Air pollutants, Greenhouse gases, Waste heat and Noise)
Ngo and Pataki (2008)	inputs of resources		outputs of pollution (waste and greenhouse gas emissions)
Baccini and Brunner (1991)		To nourish, recover; to clean; to reside and work; to transport and communicate (4 major urban activities)	
Barles (2009)	- Unused local extraction - Local extraction(fossil fuels, minerals, and biomass) - Imports(fossil fuels, raw materials, etc.) - Indirect flows associated with imports	In society/economy - Material accumulation - Material throughput -recycling(local,external)	- Unused local extraction -To nature (emissions to air and water, wastes landfilled and dissipative flows) - Exports except wastes - Indirect flows associated with exports
Barles et al. (2011)	- Food import	- Food consumption	- Food waste - Food export
Venkatesh and Brattebø (2011)	-Water supply system	-Water treatment, distribution and demand subsystem -Storm- & wastewater drainage subsystem -Wastewater treatment subsystem -Storm- & waste water discharge & Re-use subsystem	-Waste -Emissions (all coming from the subsystems of the internal processes)

Haberl, 2011	- Imports - Domestic extraction	- Material stocks (buildings, machinery etc.) - Material throughput - Energy provision - Energy consumption	- Exports - Residues - Wastes - Emissions
Spiller and Agudelo, 2011	Food, water, energy(heat, gas, and electriciy)	Urban metabolic element	Heat loss, water, carbon, nutrients, pathogenes
Ngo and Pataki (2009)	- Fuel - Electricity - Water import - Precipitation - Food - Other materials	Transformations of matter and energy - Local energy generation - Groundwater - Surface water - Food production	- Air pollution - Greenhouse gases - Waste heat - Water pollution - Evapotranspiration - Stormwater runoff - Wastewater discharge - Solid waste - Water pollution
Kennedy et al., (2011)	- Energy - Water - Nutrients - Materials - Wastes	Storage of materials and energy	- Energy - Water - Nutrients - Materials - Wastes
Korhonen,2011	Solar energy		Waste heat
Decker et al, 2000	-Stored inputs (construction and waste) -transformed inputs(food, fuel, water) -passive inputs(air, water, heat)		-atmospheric outputs -aquatic and marine outputs -earth system linkages