TAMPEREEN TEKNILLINEN YLIOPISTO

NOORA MIETTINEN

THE ROLE OF BIOENERGY IN THE ENERGY SYSTEMS OF FUTURE CITIES

Master of Science Thesis

Examiners: Professor Jukka Rintala and Professor Risto Raiko
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ABSTRACT

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The population growth in cities is expected to continue both worldwide and in the case countries Finland and Germany, and hence the importance of cities is increasing. Official climate and energy targets define guidelines for the transition of urban energy systems, but cities have also their own strategies and specific characteristics that affect the development. Literature review on implemented bioenergy projects and on municipal energy planning proved that suitable political framework is considered as a crucial driver and a factor for successful execution of renewable energy projects.

National and EU-level strategies include high targets for increasing renewable energy production capacity, and also bioenergy is planned to have a significant role in the future. Analyzed strategies of ten case cities were noticed to be mainly based on the upper-level targets. The specifity of the municipal strategies varied greatly, and thus detailed estimations on the characteristics of future urban energy systems were difficult to assess. The most often mentioned bioenergy-related measures in the analyzed strategies were usage or production of biogas, energetic utilization of waste, increasing usage of biofuels in traffic and small-scale bioenergy-based heating systems.

Since the municipal strategy documents contained rather general-level plans for the utilization of bioenergy, the most potential bioenergy technologies for urban environments were evaluated based on a literature review. Important factors for urban bioenergy technologies are especially adjustability, storability, efficiency and potential to utilize local resources. Considering also the development statuses of technologies, it was concluded that at least combined heat and power and possible also cooling production by fluidized-bed combustion or co-combustion are among the most potential technologies. Feedstock for combustion can be different waste flows or upgraded biomass, depending on the locally available resources in each city. Also biogas production from biowaste and sewage sludge has great potential in cities with existing gas network, due to various potential applications and easy storability and distribution.

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Kaupungistumisen odotetaan jatkuvan niin maailmanlaajuisesti kuin esimerkkimaissa Suomessa ja Saksassakin, joten kaupunkien merkitys todennäköisesti kasvaa tulevaisuudessa. Viralliset ilmasto- ja energiatavoitteet luovat suuntaviivat kaupunkien energiajärjestelmien muutokselle, mutta myös kaupunkien omat strategiat ja erityispiirteet vaikuttavat kehitykseen. Kirjallisuuskatsaus toteutetuista bioenergiahankkeista ja kaupunkien energiajärjestelmien suunnittelusta todistaa, että sopiva poliittinen viitekehys on tärkeä menestystekijä ja motiivi uusiutuvan energian projektien menestyksekkäässä toteuttamisessa.

Kansallisissa ja EU:n energiastrategioissa määritellään korkeat tavoitteet uusiutuvan energian tuotantokapasiteetin lisäämiselle, ja myös bioenergialle on suunniteltu entistä tärkeämpi rooli tulevaisuudessa. Analysoidut kymmenen esimerkkikaupungin strategiadokumentit pohjautuvat pitkälti ylemmän tason poliittisiin tavoitteisiin. Strategioiden yksityiskohtaisuus vaihtelee huomattavasti kaupunkien välillä, ja niinpä tarkkoja arvioita tulevaisuuden kaupunkien energiajärjestelmien piirteistä on vaikea tehdä. Kaupunkien strategioissa useimmiten mainittuja bioenergiaan liittyviä toimenpiteitä ovat biokaasun tuotanto ja käyttö, jätteen hyödyntäminen energiana, liikennebiopolttoaineiden lisääntyvä käyttö sekä pienen mittaluokan bioenergiaan perustuva lämmöntuotanto.

Tärkeimpiä tekijöitä kaupunkiympäristöihin soveltuville bioenergiatekniikoille ovat kirjallisuuden perusteella erityisesti säädettävyys, varastoitavuus, tehokkuus ja mahdollisuus paikallisten raaka-aineiden hyödyntämiseen. Kun myös eri teknologioiden arvioidut kehitysasteet huomioidaan, voidaan päätellä, että ainakin yhdistetty lämmön- ja sähkön- ja mahdollisesti myös kylmäntuotanto leijupolttoa hyödyntäen on potentiaalisimpien teknologioiden joukossa. Polttoaineena voidaan käyttää esimerkiksi eri jätevirtoja tai jalostettua biomassaa joko sellaisenaan tai rinnakkaispoltossa muiden polttoaineiden kanssa riippuen raaka-aineiden saatavuudesta kussakin kaupungissa. Myös biokaasun tuotanto biojätteestä tai jäteveden lietteistä nousee mahdollisesti entistä tärkeämpään asemaan, sillä biokaasua on mahdollista käyttää lukuisissa erilaisissa käyttökohteissa ja sitä on suhteellisen helppo varastoida ja jaella kaupungeissa, joissa on jo valmiina kaasuverkosto.

PREFACE

This thesis is part of "Sustainable Bioenergy solutions for Tomorrow" (BEST), a joint research program by CLEEN Oy and FIBIC Oy. The program is funded by the Finnish Funding Agency for Technology and Innovation (TEKES). This thesis is based on results from subtasks 3.1.1 and 3.1.3 of the project. I want to thank all the representatives from companies and universities who were participating in the work package 3.1 and thus co-operating in the working process. Especially Marja Englund and Matti Sonck from Fortum Oyj were closely involved in the thesis writing process.

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I started working for the BEST project at the end of September 2013 and the work on the thesis started properly in May 2014. However, all the knowledge and results gained during the project were valuable for this thesis.

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Contents

LIST OF SYMBOLS AND ABBREVIATIONS

AD	Anaerobic digestion
BFB	Bubbling fluidized-bed boiler
CFB	Circulating fluidized-bed boiler
CHP	Combined heat and power production
CCHP	Combined cooling, heating and power production
EU	European Union
GHG	Greenhouse gas
GDP	Gross domestic product
HDI	Human development index
ICT	Information and communication technologies
IGCC	Integrated gasification combined cycle
IGFC	Integrated gasification fuel cell cycle
MSW	Municipal solid waste
NREAP	National Renewable Energy Action Plan
ORC	Organic Rankine cycle
SOFC	Solid oxide fuel cell
R&D	Research and development
WWTP	Wastewater treatment plant

1 INTRODUCTION

The importance of cities as energy consumers is growing since the share of urban population is increasing both worldwide and in the European Union (EU) (Savolainen et al. 2009; Population Reference Bureau 2103). In addition to population growth, also national and international climate and energy targets accelerate the transition of urban energy systems. City areas have the potential to create modern solutions for combining energy flows and demand various energy forms due to the typical characteristics of urban environments such as high population density. Yet another driver for implementation of modern energy solutions is cities' aim to achieve a reputation of being forerunners in climate friendly technologies.

In order to study expected development of urban energy systems, in total ten cities were selected from case countries Finland and Germany for analysis. Especially cities with the greatest population number were searched, as well as cities that have a reputation of being forerunners in energy-related issues. To get a more diverse sample of cities, cities from different parts of the countries were selected as well as some smaller cities.

Many changes that affect urban energy systems are expected to occur in the near future. The case countries Finland and Germany have significant plans to increase renewable energy production, to improve energy efficiency and to lower greenhouse gas (GHG) emissions. Development trends for urban environments can also be found in scientific literature. Introduction of smart cities contribute to better optimization of energy and material flows by improved utilization of information and communication technologies (ICT) (Bakici et al. 2013; Neirotti et al. 2014). Urban harvesting is a modern viewpoint to cities as resource reservoirs and producers of secondary resources for e.g. energy production (Agudelo-Vera 2012; Leduc et al. 2012). A common aim for many cities worldwide is to become low-carbon or carbon regions (Reiche 2010; Su et al. 2013). The role of municipal planning in implementation of energy-related projects in cities is significant (Measham et al. 2011; Sperling et al. 2011).

The aim of this study is to analyze targeted development of urban energy systems especially in Finland and Germany and to evaluate the role of bioenergy and various potential technologies. Firstly, theoretical background is presented in chapters 2 and 3. In chapter 2, common development trends and targets of city development are presented. In addition, characteristics of urban energy demand and planning of municipal energy systems are discussed. In chapter 3, energy-related targets and strategies of national and EU-level are described. In chapter 4, ten cities from Finland and Germany are selected as case cities. General characteristics of the case cities are described as well as the current energy consumption and existing energy infrastructure.

In chapter 5, findings from the analysis of municipal climate and energy strategies are described and discussed. The aim is to identify drivers for energy systems development as well as common development trends with the focus on the role of bioenergy. Also the scope of the strategies and main differences between the cities are analyzed.

Lastly, potential bioenergy technologies are described based on a literature review and their suitability for urban environments is discussed. Research trends related to analyzed technologies are presented as well as estimates on the development status of each technology. Results of the technology review are reflected to the conclusions from the cities' strategies in order to create a vision of the role of bioenergy in urban energy systems in the future.

2 FUTURE CITY STRUCTURES

In Europe, 71% of the population lives in urban areas and the corresponding percentages for Finland and Germany are 68% and 73%, respectively (Population Reference Bureau 2013). In the statistics of Population Reference Bureau, each country has defined the term "urban area" on their own or alternatively the definition of the United Nations is used and therefore there are several different definitions. The urbanization is expected to continue in the upcoming decade (Quigley 2008; Ponce de Leon Barido et al. 2014), which means that new urban areas will be constructed and old infrastructure is renovated. In the EU, 80% of total final energy consumption can be traced to cities (Cerutti et al. 2013). The development of city structures has an impact on urban energy demand and on the optimal energy production and distribution methods.

2.1 Urban energy demand

Energy is needed in cities for a variety of actions. Number of inhabitants and energy consumption per capita form the urban energy demand excluding energy consumption of industry. Energy consumption per capita depends on lifestyle and technological aspects of available devices. Fundamentally, the amount of energy consumed depends on individual choices. (Viinikainen et al. 2009) Many characteristics of cities affect the demand for energy: population density, public transportation systems, eco-efficiency of buildings and transport, energy systems and land use.

One of the crucial factors that affect the demand for energy is the average population density, since there is a strong negative correlation between energy use in transport and population density. In addition, city structures affect the energy consumption of the traffic sector. The average commuting distances and locations of shopping and leisure time centers in relation to residential areas also affect energy demand in the transport sector. (Viinikainen et al. 2009)

Energy efficiency of new and existing building stock influences especially demand for heat. Energy efficiency can be improved by stricter building regulations, new materials and building techniques. (Viinikainen et al. 2009)

As industrial processes are often energy intensive, industry may have a remarkable effect on cities' energy consumption. The amount of demanded energy depends on the production volume, type of process, energy efficiency and possibilities to utilize secondary energy from the process itself. (Viinikainen et al. 2009) However, industrial energy demand will be given less attention in this study.

2.2 Energy system development

Targets of cities for future energy systems can be identified from official strategies and agreements, but it is also important to understand what reaching the targets requires. In this chapter, experiences from different bioenergy projects in urban environments are summarized and characteristics of municipal energy planning are shortly described.

2.2.1 Experiences from implemented bioenergy projects

Several driving forces, risks and challenges and success factors from different kinds of bioenergy and waste management projects in European cities are described in literature, e.g. in Madlener et al. (2007, 2008), Johnson et al. (2011) and Anthonis et al. (2013) (figure 2.1). The studied projects relate to large-scale bioenergy cogeneration plants, introduction of biodiesel in the car fleet and urban waste management systems.

- Drivers
- willingness of forest owners to create demand for biomass
- previous experiences of the region in implementing new sustainable technologies and willingness to continue with new projects
- aim of the local energy company to gain a green certificate
- willingness to achieve a good image for the city/company by introducing renewable energy production capacity
- awareness of an existing problem that need a solution

- Risks and challenges
- political risk
- wood-fuel supply and on-site logistics
- development of waste wood market
- lack of comprehensive political framework
- lack of a monitoring program
- insufficient general knowledge and misunderstandings of environmental and social aspects
- design of the fuel supply logistics
- public opposition

- Success factors
- study tours to existing plants
- interests of different actors must be balanced
- use of existing location with existing infrastructure, installations and services
- by using a location that has had plants before reduces public opposition
- active role of change agents
- economic support
- political consensus about desirability of the plants
- fuel supply should be organized at an early stage of the project
- high capital investments
- development of new institutes
- technological and organizational knowledge
- strong interaction and co-operation between the city and research institutes
- a relatively high political independence of municipalities from the national government
- national legislation in line with the policies of municipalities
- EU-level policies and regulations

Figure 2.1. *Driving forces, risks and challenges and success factors of the analyzed urban bioenergy projects (Madlener et al. 2007, Madlener et al. 2008; Johnson et al. 2011; Anthonis et al. 2013)*

Following a strategy that favors the introduction of new sustainable plants that contribute to the creation of a green city image is mentioned as one of the main driving forces behind many projects (figure 2.1). Political risks and a lack of a comprehensive political framework were noticed to be barriers for successful bioenergy projects, whereas economic support and political will to carry out the project are among the success factors. Suitable independency of the city in decision making is mentioned to be favourable for the creation of innovative solutions, but municipal policies should be in line with national legislation. Higher level targets, for example the policies of the EU, are also assumed to support the development process. In addition, co-operation between the city and research institutes contributes to the introduction of innovative solutions. Various other factors are mentioned as well, but the existence of political and legislative frameworks seems to be an important aspect for drivers, risks and challenges as well as success factors.

Figure 2.1 summarizes the experiences from four bioenergy related projects but it does not contain a complete collection of drivers, risks and challenges and success factors. The obligation to reach binding upper-level targets is not mentioned in the analyzed articles, but it can be considered as one of the most important driving forces behind the implementation of renewable energy projects.

Furthermore, technological risks must be taken into account, especially when introducing modern bioenergy technologies. Also risk of demand may be determining: for instance, demand for district heating production may decrease significantly if heat pumps and ground heat systems continue to become more common and if energy efficiency of buildings improves notably. In the electricity sector, changes in production capacity in other regions and countries from the same market area affect electricity demand and prices and must therefore be anticipated when contemplating new investments. Security of fuel supply can be critical to profitability of bioenergy plants and therefore adequate feedstock capacity, preferably nearby the plant, could be listed as a success factor.

2.2.2 Planning of municipal energy systems

Suitable political framework both on local and upper level was noticed to be an important factor for successful implementation of bioenergy projects (figure 2.1). The role of municipal planning is also highlighted in Measham et al. (2011), where adaptation to climate change is analyzed. It is argued that there are several constraints that weaken municipal planning. The main constraints review were argued to be lack of information (Crabbe et al. 2006; Mukheibir et al. 2007), institutional limitations (Ivey et al 2004; Wild River 2006) and resource constraints (Brackertz et al. 2002; Crabbe et al. 2006; Pini et al. 2007). Upper-level policies are mentioned to affect municipal planning so much that cities have limited decision power. Lack of resources, especially financial capacity, can lead to implementation of short-term solutions instead of more comprehensive long-term approaches. (Measham et al. 2011)

As municipal climate and energy strategies will be analyzed later in this thesis, the role of municipal strategies is assessed based on Sperling et al. (2011). Municipal energy plans can be used for evaluating the focus areas and ambitions of the cities in energy planning, whereas conclusions on implementation can be drawn by comparing the focus areas and corresponding institutional frameworks. It is also recommended that synergies between cities should be supported and sub-optimization avoided by central coordination. However, the policies and legislation should be flexible enough so that municipalities implement the most suitable actions of the national focus areas. (Sperling et al. 2011)

2.3 Development trends of urban areas

Three general development trends were identified in literature on future city structures. Concepts “smart city”, “urban harvesting” and “carbon neutrality” are desired characteristics in the future and also intensively studied. The concepts “smart city”, “urban harvesting” and “carbon neutrality” are shortly described in this chapter. The target behind all the concepts is sustainability as a result of efficient utilization of resources and environmentally friendly technologies (table 2.1).

Table 2.1. *Characteristics of development trends of future city energy structures (Agudelo-Vera, C. 2012; Leduc et al. 2012; Su et al. 2013; Neirotti et al 2014)*

	Carbon neutrality	**Smart cities**	**Urban harvesting**
Core targets	Reduction of GHG emissions	Advanced utilization of ICT for better sustainability	Efficient utilization of cities' own resources
Possible effects on energy systems	Increasing usage of low-carbon energy production technologies	Efficient usage of resources, optimization of operation of various energy production units	Increasing utilization of local resources, especially secondary resources, diversity of feedstock

2.3.1 Smart cities

Smart cities are characterized by extensive utilization of ICT that improve the economic, social and environmental sustainability of cities. As a result, also usage of various resources for example for energy production will become more efficient. However, a commonly approved definition of the term “smart city” is still lacking. (Bakici et al. 2013; Neirotti et al 2014)

In order to create smart cities, centralized planning and control is needed. Data from various functions of the city is collected via ICT systems, e.g. from thermostats of buildings, traffic lights and parking spaces. (Neirotti et al 2014) In addition, advanced weather forecasts and real-time information about for instance temperatures, windiness and solar radiation improve operation of various energy production plants. According to Neirotti et al (2014), the collected data is used real-time for optimization of various operations and for decision making. In addition to increasing and improved utilization of ICT, smart city concept can also be considered to include investments in human capital and changed urban living conditions and practices. Also the actions city governments and the cities' innovation capacity can be considered as parts of smart cities. (Neirotti et al 2014)

2.3.2 Urban harvesting

Typically, cities in industrialized countries need resource and energy imports from hinterlands, and export waste streams that still contain many valuable components. A concept called "urban harvesting" means efficient utilization of cities' own renewable and secondary resources such as grey water, rain water wind power or solar energy. The aim of urban harvesting is to create closed-loop energy and material flows and to minimize demand. Various local resources and different actions are linked together to form a flexible network that allows temporary shortage of some of the resources. Urban harvesting also increases the cities' self-sufficiency thus making them less susceptible to external changes. (Agudelo-Vera, C. 2012; Leduc et al. 2012)

Prerequisites for urban harvesting include detailed inventory of the quantity, quality location and temporal characteristics of available resources. In addition, land-use planning, building of suitable infrastructure and storage capacity are needed. (Agudelo-Vera, C. 2012; Leduc et al. 2012) Development of smart cities can also contribute to introduction of urban harvesting, since data from various actions can also include information about demand available resources.

2.3.3 Carbon neutrality

For many cities a common target is the aim to become a low-carbon or carbon free city (chapter 5) (Reiche 2010; Su et al. 2013). However, the definition low-carbon city is not unambiguously defined. In Su et al. (2013), several commonly used indicators for measuring the level of carbon neutrality are presented. It is argued that both comprehensive evaluation and concrete analysis are needed to define low-carbon characteristics of a city. Commonly used indicators include economic development, social progress, energy structure, living consumption and environmental quality. (Su et al. 2013)

The most obvious aim of cities who pursue carbon neutrality is to reduce GHG emissions. However, also other aspects should be considered, such as economic development, social justice and low-carbon life-style. To find the most suitable development path towards carbon neutrality, also special characteristics of each city, for instance available local resources and socio-economic situation, should be identified. (Su et al. 2013)

3 POLITICAL AND LEGISLATIVE FRAMEWORK OF ENERGY SYSTEM TRANSITION

Energy is considered as a vital resource for modern societies and hence energy must be produced and delivered economically, ecologically and reliably. Therefore, various binding and non-binding energy targets and strategies have been drawn up for instance by the European Commission and national governments to develop and retain sustainable energy systems and sufficient security of supply. Upper-level targets and strategies guide the directions of development in cities; hence the most important targets in Finland and Germany are briefly described in this chapter.

3.1 Energy related regulations and targets of the European Union

The latest update in the energy policies of the EU in 2014 is the policy framework for climate and energy in the period from 2020 to 2030 that has been proposed by the European Commission. The leaders of the Member States have not yet decided on the framework, thus it is not yet confirmed. The new policy assumes that the targets for 2020 have been implemented and development continues towards 2050 as defined in the roadmap. The aim is to improve regional co-operation and flexibility to consider local strengths and challenges to reach the climate and energy targets in the most cost-efficient way. Proposed numerical targets address reducing GHG emission by 40% compared to 1990, and increasing the share of renewable energy sources in final energy consumption to at least 27%. (European Commission 2014)

Binding targets for the year 2020 are set in the Third energy package established in 2007). The European Union has set a target for increasing the share of energy from renewable sources in overall final gross energy consumption to 20% by 2020 and to reduce GHG emissions by 20% by 2020 compared to the level of 1990. The target is defined in Directive 2009/28/EC. Furthermore, the Directive includes a goal for the transport sector to reach a 10% share of renewable energy in energy consumption. (Directive 2009/28/EC)

To reach the 20% share of renewable energy sources, individual targets have been set for each Member State. National objectives are defined based on the countries' existing energy mix and potential for utilization of renewable energy sources. Individual targets for Finland and Germany are 38% and 18%, respectively. Starting points and goals of all Member Countries are listed in Appendix 1. By obligating the Member States to establish national targets, the EU strives to promote the development of technologies related to renewable energy sources and to provide certainty for investors. (Directive 2009/28/EC)

Contrary to other renewable energy production targets, the minimum target of 10% in the transport sector is equal for every country. By setting an equal target, the EU aims at ensuring consistency in fuel specifications and availability. Due to the fact that transport fuels can easily be traded, the Member States that are unable to produce the required amount of biofuels can import them from other countries. (Directive 2009/28/EC)

Energy efficiency and energy saving policies are considered as effective methods for increasing the share of energy from renewable sources to achieve the overall targets. The aim for all Member States is a 20% improvement in energy efficiency by 2020 compared to 2005. In addition, the Directive 2009/28/EC obliges all Member States to establish National Renewable Energy Action Plans (NREAPs), where they define separate renewable energy targets for different sectors, set out measures on how to achieve the targets and evaluate the expected gross final energy consumption taking into account the impact of energy efficiency and energy saving methods. (Directive 2009/28/EC)

The EU's long-term energy strategy is defined in a document "Roadmap for moving to a low-carbon economy in 2050" published in 2011. The main goal of the roadmap is to provide information on measures that assist on cutting the GHG emissions by 80% by 2050 compared to the levels of 1990. It is estimated that if the development towards a low-carbon society would occur as planned, total primary energy consumption could be 30 % lower in 2050 than in 2005. (European Commission 2011)

3.2 Finland's national targets for renewable energy production and energy efficiency

The most significant documents defining national energy and climate policies of Finland are the "Long-term Climate and Energy Strategy" and the NREAP. The Finnish Government has laid out detailed targets and measures for promoting utilization of renewable energy sources in the "Long-term Climate and Energy Strategy" first published in 2008. The targets are based on the goals that were set for Finland by the European Commission in Directive 2009/28/EC. The strategy has been updated in March 2013 to ensure that the targets will be reached and to get prepared for longer-term goals. (Ministry of Employment and the Economy 2013)

In the "Long-term Climate and Energy Strategy", target for the share of renewable energy in final gross energy consumption is 38%, as defined in Directive 2009/28/EC, but in the transport sector the goal is set higher. Although the common objective for all EU countries is to have 10% of the energy used in the transport sector produced from renewable energy sources, Finland aims at having a share of 20%. (Ministry of Employment and the Economy 2013)

The Ministry of Employment and the Economy has calculated estimations on the development of energy consumption in Finland until 2020 in co-operation with other ministries for the update of "Long-term Climate and Energy Strategy" in 2013 (table 3.1). The results of the calculation show that the estimated final gross energy consumption of

Finland in 2020 is 325 TWh taking into account the measures defined in the "Long-term Climate and Energy Strategy" from 2008 and the decisions of principle of the parliament about nuclear energy and alignments of the government about the NREAP from 2010. In the elaborated basic scenario, also additional measures defined in the update of the "Climate and Energy Strategy" from 2013 are considered. The target of the "Long-term Climate and Energy Strategy" is to adopt new measures to control the increase in energy consumption and thus limit the final gross energy consumption of Finland to 310 TWh in 2020.

Table 3.1. *Energy scenarios of Finland according to Long-term Energy and Climate Strategy. (Ministry of Employment and the Economy 2013)*

Source	Statistics	Basic scenario from 2013	Elaborated basic scenario from 2013	Target scenario from 2008
Year	**2010**	**2020**	**2020**	**2020**
Primary energy gross consumption, TWh	407	433	426	429
Renewables, TWh	110	135	134	130
Industrial liquor, TWh	38	39	39	38
Industrial residual wood, TWh	20	18	18	22
Other wood, TWh	31	40	38	37
Wind power, TWh	0.3	6	6	6
Oil, TWh	98	91	88	83
Final energy consumption, TWh	323	325	317	310
renewables, TWh	104	128	127	118
Electricity consumption, TWh	88	93.8	93.3	98
Renewables, TWh	24	33	33	33
Renewables, %	28	35	35	33
Traffic, TWh (exc. electricity)	50	49	47	48
RES % of final consumption	32.2	38.8	39.4	38
GHG-emissions, Mt CO_2-equivalent	75	65	63	N/A
Sectoral electricity consumption, TWh				
Industry and construction	42	47	48	56
of which pulp and paper industry	20	21	21	N/A
Home devices	10	10	10	13
Electrical heating (inc. heat pumps)	13	13	12	8
Services	18	19	19	16
Other consumption, losses	4	5	5	5

Scenarios from 2008 and 2013 are not entirely comparable since the calculation methods and statistics have changed. However, it is noticed that the differences between the scenarios are relatively small: targeted primary energy consumption is 0.7% smaller and primary renewable energy consumption 3.1% bigger in the elaborated basic scenario from 2013 than in the target scenario from 2008. (Ministry of Employment and the Economy 2013)

The NREAP of Finland was compiled in 2010 under the terms of the Directive 2009/28/EC. The NREAP contains a detailed plan about how to reach the renewable energy targets set by the EU including a description of expected renewable energy technology mix (Appendix 2), sectoral targets as well as prospective measures and reforms. (Ministry of Employment and the Economy 2010)

The NREAP contains estimations about the development of Finland's energy consumption in the electricity, heating and cooling and transport sector until 2020 (table 3.2). The estimates are prepared by taking into account energy saving and efficiency measures and the target of improving energy efficiency by 20%. (Ministry of Employment and the Economy 2010)

Table 3.2. *Expected gross final energy consumption in Finland in 2005-2020 (Ministry of Employment and the Economy 2010)*

	2005 (TWh)	2015 (TWh)	2020 (TWh)
Heating and cooling	162	174	178
Electricity	88	95	102
Transport	49	48	47
Gross final energy consumption	305	319	328

According to the NREAP, wind power production will increase from 150 GWh in 2005 to 6 TWh by 2020. The increase is promoted by feed-in-tariffs and an annual sum of 1.5 million euros earmarked for supporting the planning of wind power. (Ministry of Employment and the Economy 2010)

A significant increase is expected also in the use of biomass. Power production from biomass is estimated to be 12.9 TWh in 2020, whereas the overall generation in 2005 was 9.7 TWh. The biggest increase is planned for solid biomass, especially for wood chips and other wood fuels. To promote the use of wood fuels, a three-part package has been adopted including feed-in-tariffs for wood chips and small-scale combined heat and power (CHP) plants and energy support for small-sized wood. (Ministry of Employment and the Economy 2010)

In the transport sector, the use of biofuels is aimed to be risen to 7 TWh by 2020.The growth is planned to occur via a distribution obligation for vendors of transport fuels and a tax reformation. Domestic production of biofuels is estimated to have the potential to cover approximately 15 % of the 7 TWh target if new capacity will be constructed. (Ministry of Employment and the Economy 2010)

3.3 Germany's national targets for renewable energy production and energy efficiency

The most significant documents that define the energy policy of Germany include the "Energy Concept", the NREAP and regional strategies of the federal states. Other important documents are for example the "Renewable Energy Sources Act" and the "Renewable Heat Act" that contain a definition of support measures for renewable energy production. (Federal Republic of Germany 2010; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011; Der Deutsche Bundestag 2011, 2012)

Germany's long-term strategy for future energy supply is defined in the "Energy Concept", which was adopted in September 2010. The "Energy Concept" contains targets to be reached by 2050 and various actions planned for supporting the development. Part C of document, which describes the future role of nuclear energy, has been replaced by the information provided in the "Energy Package" adopted in June 2011 after the Federal Cabinet enforced the new Atomic Energy Act. The "Energy Package" from 2011 also strives to accelerate the reaching of the targets defined in the "Energy Concept". (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011)

Official targets for increasing the share of renewable energy in final energy consumption and improvement in energy productivity are also announced in the Energy Concept. The share of renewable energy in the final energy consumption is expected to be 18 % in 2020 as defined in EU's policy and the development is planned to be continued in the years 2020-2050 (table 3.3). (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011)

Table 3.3. *Share of renewable energy in final energy consumption in Germany in 2005-2050 (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011)*

	2005 (%)	2020 (%)	2030 (%)	2040 (%)	2050 (%)
Share of energy from renewable sources in gross final consumption of energy	5.8	18	30	45	60

Primary energy consumption is aimed to be cut by 20% by 2020 and by 50% by 2050 compared to the level of 2008. To reach the target, energy productivity should be improved by 2.1% annually. An increase in the building renovation rate from the existing less than 1 % to 2% of the total building stock per year is needed to support the decrease in energy consumption. The percentage reduction in energy consumption in the transport sector is expected to be 10% by 2020 and 40% by 2050. Furthermore, 1 million electrical vehicles are targeted to be in use in 2020 and 6 million in 2030. (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011)

The NREAP was published before Germany's "Energy Concept", thus it does not contain the latest information in all fields. Two different scenarios for the development of gross final energy consumption are described in the NREAP: reference scenario (REF) and scenario with additional energy efficiency measures (EFF). REF considers only the energy efficiency and energy saving measures adopted prior to 2009, whereas EFF assumes that additional measures will be taken. In both scenarios, gross final consumption of energy will decrease significantly compared to the base year 2005 (table 3.4). In the EEF, gross final energy consumption decreases by 13.9% in 2005-2020 and in the REF the decrease is 7.6%. The most substantial decrease is expected to occur in the heating and cooling sector, where the decrease is 20.3% according to the EFF and 15.5% according to the REF. (Federal Republic of Germany 2010)

Table 3.4. *Expected gross final energy consumption in Germany in 2010-2020 (Federal Republic of Germany 2010)*

	2005	2015		2020	
	Base year (TWh)	Reference scenario (TWh)	Scenario with additional energy efficiency measures (TWh)	Reference scenario (TWh)	Scenario with additional energy efficiency measures (TWh)
Heating and cooling	1359	1235	1205	1149	1083
Electricity	603	611	588	612	562
Transport	623	607	596	605	562
Gross final energy consumption	2664	2546	2479	2461	2293

It is estimated that a share of 19.6 % of final energy consumption will be produced from renewable sources in 2020 according to current development and plans. The greatest share of renewable energy is assumed to be in the electricity sector and the lowest in the transport sector (table 3.5).

Table 3.5. *Estimated share of renewable energy in final energy consumption in the sectors electricity, heating and transport in 2020 (Federal Republic of Germany 2010)*

	Electricity (%)	Heating (%)	Transport (%)	Total (%)
Share of renewable energy in final energy consumption	38.6	15.0	13.2	19.6

In order to achieve a 38.6 % share of final electricity consumption produced from renewable energy sources, there should be approximately 112 TWh additional renewable energy in the electricity sector compared to 2010 (Appendix 3). The greatest absolute increase will occur in wind power: the annual production is intended to be risen by 59.8 TWh to more than 100 TWh in 2020 (table 3.6). The share of offshore wind power is estimated to be 31.5 TWh. The second biggest increase is planned for solar energy (31.9 TWh) and the third for biomass (16.7 TWh). (Federal Republic of Germany 2010)

Table 3.6. *Estimated annual electricity production amounts by wind power, solar power and biomass in 2010 and in 2020 (Federal Republic of Germany 2010)*

Annual electricity production	2010 (TWh)	2020 (TWh)
Wind power	44.7	104.4
Solar power	9.5	41.4
Biomass	32.8	49.5

In Germany, support measures for the production of renewable energy are defined in Renewable Energy Sources Act (EEG) first implemented in 2001. There is a feed-in-tariff for all forms of renewable energy, and electricity produced from renewable sources has a priority access to the national grid. The level of the tariff depends upon the production method and also on the location and capacity of the production unit. The tariff remains on the same level for each individual production unit for 20 years. However, the tariff is decreased annually so that the later the units are first connected to the grid, the lower the tariff. Producers of renewable energy are also allowed to pay reduced tariffs. In addition, there are funding programs that enable projects related to construction of new renewable energy capacity to apply for low-interest loans. (Der Deutsche Bundestag 2012)

The Renewable Heat Act (EEG-Wärme) for the promotion of renewable heat production was enacted in 2009 and updated in 2011 to supplement the EEG. The goal of EEG-Wärme is to increase the share of renewable energy in final heat energy consumption including space heating, cooling, process heat and hot water to 14% by 2020. In the EEG-Wärme, owners of new buildings of more than 50m², with some exceptions, are obligated to cover a certain share of heat demand with renewable energy. If the chosen renewable energy form is solar energy, it must cover at least 15 % of the total heat demand of the building. The corresponding percentage for biomass is 50 %, for biogas 30 % and the percentage value for geothermal energy and heat pumps is 50 %. Utilization of waste heat and district heating from CHP production is also considered as sufficient renewable energy usage if the production fulfils given efficiency requirements. In addition, the requirement can also be fulfilled by energy saving measures. Municipalities and unions of municipalities are also given the possibility to establish a connection obligation to local district heating network to promote climate and resource protection. (Der Deutsche Bundestag 2011)

In addition to national targets, the 16 federal states have their own energy and climate policies and goals. In some cases, the targets are set higher that the mandatory level. For instance Lower Saxony, Thuringia and Rhineland-Palatinate plan to increase the share of renewable energies in final energy consumption higher than 20%. Regional strategies also include more specific action plans than the national strategies. (Federal Republic of Germany 2010)

3.4 National bioenergy-related targets of Finland and Germany

The targeted development for usage of bio liquids, solid biomass and biogas in electricity, heating and cooling and transport is defined in the NREAPs of Finland and Germany (table 3.7). Both Finland and Germany intend to increase especially biogas production. The percentual increase is 148.9% in Finland and 76.1% in Germany. In Germany, the absolute growth is approximately on the same level for solid biomass, bio liquids and biogas. In Finland, clearly the biggest absolute growth is expected for solid biomass.

Table 3.7. *Targets for increases in biomass, biogas and bio liquid consumption in energy sector in Finland and Germany according to the National Renewable Energy Plan (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)*

Finland	Total (GWh)	Biomass (GWh)	Biogas (GWh)	Bio liquids (GWh)
2010	68.6	35.4	0.39	32.7
2020	96.3	53.7	0.97	41.6
Change 2010-2020 (%)	40.4	51.4	148.9	27.2
Germany				
2010	179.6	104.9	25.6	49.1
2020	245.2	128.7	45.1	71.4
Change 2010-2020 (%)	36.5	22.7	76.1	45.5

The strategies of both Finland and Germany for the time period until 2020 are based on the EU-level targets. Targets are not on the same level for all Member States, but they are estimated to require an equal increase taking into account each country's potential for renewable energy. The EU stipulates only the targeted share of renewables in energy consumption, Member States can decide independently how to achieve the desired share and to what extent to utilize each renewable energy source.

The expected changes in electricity production of various sources both in Finland and Germany are defined in the NREAPs (table 3.8) (note:2005 is used as a base year and production amounts are estimates for 2015 and 2020 so that total production fulfils the target in 2020).

Table 3.8. *Electricity production from renewable energy sources in Finland and Germany in 2005 and estimates for 2015 and 2020 (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)*

Year	Country	Hydropower (TWh)	Geothermal (TWh)	Solar (TWh)	Wind (TWh)	Biomass (TWh)	Total (TWh)
	FI	13.9	0.0	0.0	0.2	9.7	23.7
2005	GER	19.7	0.0	1.3	26.7	14.0	61.7
	FI	14.2	0.0	0.0	1.5	9.9	25.6
2015	GER	19.0	0.4	26.2	70.0	4.2	157.6
	FI	14.4	0.0	0.0	6.1	12.9	33.4
2020	GER	20.0	1.7	41.4	104.4	49.5	216.9
Change 2005-	FI	4	N/A	N/A	3 960	34	41
2020 (%)	GER	2	N/A	3 128	292	253	252

The most notable difference for electricity production lies in solar energy. Finland has no significant plans for constructing solar energy plants, whereas Germany aims at increasing the annual production by more than 40 TWh (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010). The most obvious reason for the difference is Germany's location; in southern Germany the intensity of solar radiation is more favorable for efficient solar energy production than in Finland. In Germany, the yearly sum of global irradiation is typically in the range of 1 100-1 400 kWh/m^2 whereas in Finland the corresponding values are in the range of 900-1 100 kWh/m^2 (Šúri et al. 2007; Huldt et al.2012).

Both countries are planning a significant increase in wind power production: Germany intends to increase the production by approximately 78 TWh and Finland by approximately 6 TWh. Also utilization of biomass for power production is expected to clearly increase both in Finland and Germany by 2020. In Finland, power production from biomass has traditionally had an important role especially due to the strong pulp and paper industry. The increase of 3.25 TWh is planned to occur via greater use of solid biomass such as woody biomass. In Germany, biomass had a minor role in power production in 2005, but the amount of annually produced biomass-based electricity is expected to grow up to by 35 TWh by 2020. (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)

The sectoral distribution of renewable energy consumption is calculated based on the expected sectoral energy consumption in 2015 and 2020 and targeted shares of renewable energy in NREAPs (table 3.9). The energy consumption estimates are based on a scenario where current energy saving and energy efficiency measures are taken into account. (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)

Table 3.9. *Sectoral consumption of renewable energy in Finland and Germany in 2005 and estimates for 2015 and 2020 (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)*

Finland	**2005 (TWh)**	**2015 (TWh)**	**2020 (TWh)**	**Change 2005-2020 (%)**
Heating and cooling	65.0	73.3	85.4	31.4
Electricity	23.6	25.8	33.5	41.9
Transport	0.0	5.7	9.5	N/A
Total	88.0	104.0	124.5	41.5
Germany				
Heating and cooling	89.7	144.5	178.0	98.5
Electricity	61.5	163.8	236.3	284.4
Transport	24.3	42.5	79.8	228.3
Total	173.2	343.7	482.3	178.5

The sum of all produced renewable energy is expected to rise by 36.5 TWh in Finland and by 309 TWh in Germany. The relative increase is significant in all sectors, but the greatest in electricity both in Finland and Germany. (Federal Republic of Germany 2010; Ministry of Employment and the Economy 2010)

In addition to national and EU-level strategies, cities also have voluntary commitments and memberships of alliances of municipalities that have their own renewable energy, energy efficiency and CO_2 emission reduction targets affecting the development of energy systems of cities. For example, "Covenant of Mayors" is a movement that supports and promotes regional actors in the Member States in their actions in climate protection (Covenant of Mayors 2014). The Finnish Ministry of Employment and the Economy administers two programs on energy efficiency in the municipal sector for the time period 2008-2016, two programs for the time period 2008-2016, one for smaller and one for bigger municipalities (Ministry of Employment and the Economy 2014). All the German case cities are members of the "Climate Alliance", an European network whose member cities are voluntarily committed to reduce their CO_2 emissions by 10% every five years and halve their per capita emissions by 2030 from the level of 1990 (Climate Alliance 2014).

4 CHARACTERISTICS OF THE CASE CITIES

In order to create a more concrete view on future city energy systems, in total ten cities from Finland and Germany were selected as case cities for a further study. Selection criteria, general characteristics as well as current energy infrastructure and consumption of the case cities are described in this chapter.

Both Finland and Germany are located in Europe, have rather similar areas, gross domestic productions (GDPs) per capita and human development indexes (HDIs) but in terms of population number Germany is significantly bigger (table 4.1).

Table 4.1. *Characteristics of case countries Finland and Germany (European Commission, Eurostat 2013; European Commission, Eurostat 2014a; European Commission, Eurostat 2014b; United Nations 2014*

	Population	Land area (km²)	GDP per capita (e)	HDI
Finland	5 451 270	338 433	36 486	0.879
Germany	80 780 000	357 134	33 889	0.911

4.1 Selection of the case cities

Considerations for the selection of the case cities were geographical diversification and relatively high population numbers. For comparison, cities with various population numbers were selected. The focus was on forerunner cities that are most likely among the first ones to adopt new energy technologies. Selected case cities were Espoo, Joensuu, Tampere, Turku, Vaasa, Berlin, Freiburg im Breisgau, Hamburg, Munich and Wuppertal (table 4.2).

Table 4.2. *Selected case cities with general information and population forecasts (Statistik-Datenbank Wuppertal 2007; Statistisches Amt für Hamburg und Schleswig-Holstein 2010; Landeshauptstadt München 2011; Destatis 2012; Senatsverwaltung für Stadtentwicklung und Umwelt 2012; Tilastokeskus 2012; Tilastokeskus 2013)*

City	Population number			Change in population(%)		Land area (km²)	Population density (1/km²)	Location
	2011	2020	2030	2011-2020	2020-2030			
Espoo	252 439	281 970	306 965	11.7	8.9	312	809	Capital area, South coast
Joensuu	73 758	76 149	77 878	3.2	2.3	2 382	31	North Karelia, East inland
Tampere	215 168	229 609	241 978	6.7	5.4	525	410	Pirkanmaa, West inland
Turku	178 630	185 500	191 503	3.8	3.2	246	726	Varsinais-Suomi, South-West coast
Vaasa	60 398	64 765	68 435	7.2	5.7	364	179	Ostrobothnia, West coast
Berlin	3 501 872	3 698 000	3 756 000	5.6	1.6	892	3927	North-East inland
Freiburg im Breisgau	229 144	228 392	229 506	-0.3	0.5	153	1497	South-West inland, Baden-Württenberg
Hamburg	1 798 836	1 842 400	1 853 800	2.4	0.6	755	2382	North coast
Munich	1 378 176	1 517 039	1 591 968	10.1	4.9	311	4436	South inland
Wuppertal	349 470	330 421	N/A	-5.5	N/A	168	2075	East Inland, North-Rhine Westphalia

To analyze renewable energy-related targets of the cities, promoted technologies and scope of plans, various energy and climate strategies as well as scenario reports of the cities were searched. Several relevant documents were identified for each of the case cities (tables 4.3 and 4.4).

Table 4.3. *Energy-related strategy and scenario documents and participating bodies of the Finnish case cities*

City	Energy-related documents	Participating bodies
Espoo	Climate strategy of the capital region of Finland (2007)	cities, council of the region
	Municipal report on renewable energy (2012)	city, energy company, consultant companies
Joensuu	Joensuu Metropolitan Area's climate strategy (2009)	cities, council of the region
	Climate program of Joensuu 2013 (2014)	city
Tampere	Tampere Metropolitan Area's Climate Strategy 2030 (2010)	cities, council of the region
	Climate and energy strategy of Pirkanmaa (2014)	council of the region, representatives from various interest groups in the region
Turku	Climate strategy of Southwest Finland 2020 (2011)	council of the region, municipal energy company, service center, representatives of other interest groups in the region
	Energy Strategy of Southwest Finland 2020(2011)	cities, council of the region, governmental centre for economic development, transport and the environment, representatives from various interest groups in the regions
	Strategy 2013-2016 (2012)	municipal energy company
Vaasa	Region Ostrobothnia's energy strategy and action plan 2010-2020 (2012)	council of the region, technology center

Table 4.4. *Energy-related strategy and scenario documents of the German case cities*

City	Energy-related documents	Participating bodies
Berlin	Energy Concept 2020 (2011)	state, provincial government, research institute, energy agency, senate
Freiburg im Breisgau	Climate Strategy (2007)	research institute, energy agency of the region
	Freiburg 2050 - Auf dem Weg zur Klimaneutralität (2009)	research institute, energy agency of the region
Hamburg	Masterplan Climate protection (2013)	city council
	Environmental Program 2012-2015 (2012)	city
	Agreement of co-operation with E.On (2011)	city, energy company
	Agreement of co-operation with Vattenfall (2011)	city, energy company
Munich	Integrated climate plan concept for Munich and five participating communities (2013)	council of the region, research company , consultant company
	Energy concept of Bavaria (2011)	state council
	City development concept of Munich, guideline climate change and climate protection (2011)	city, municipal energy company, transport company
	Project plan "Ausbauoffensive erneurbare Energien"	municipal energy company
Wuppertal	Energy efficiency and climate protection in Wuppertal - strategy 2009-2020 (2009)	city, municipal energy company, waste management company
	Low Carbon city Wuppertal 2050 (2012)	research institute, energy agency of the region
	Final report of the project "Regionales Bioenergiemanagement" (2011)	cities, ministry of the state

It can be summarized that the Finnish case cities share the strategies with other municipalities in the same region whereas the German cities have their own strategies except of Munich that shares the strategy with its neighbour towns. Cities or region councils are participating in 19 of the 24 analyzed documents. Energy companies are mentioned as participants only in eight documents, but it is mentioned in many of the documents that various local interest groups have also contributed to the preparation of the documents. In addition, research institutes or consultant companies are mentioned in the working groups of nine of the strategies. Types of participating bodies behind the strategy documents were noticed to be rather similar in Finland and Germany.

4.2 Population densities and forecasts

Since the aim of this paper is to evaluate urban energy systems especially in the future, population forecasts for the case cities were searched (table 4.2). Statistic Finland has published a population forecast for all Finnish cities in 2012, and although most of the Finnish case cities have drawn up also their own population forecasts, Statistic's Finland's forecast is used in order to achieve better comparability. Population forecasts for German cities are all taken from different sources. In cases where different variations of forecasts were available, the middle or average scenario was selected.

The population number in all other cities is expected to grow, but Freiburg im Breisgau and especially Wuppertal have a negative population forecast for 2020. Wuppertal is categorized as a shrinking city with industrial history. Seven million people live in shrinking cities in Germany and therefore it is a significant city type. Typical features of shrinking cities are decreasing population number, growing number of empty dwellings, negative economic growth and incurring of a debt of private households and the public economy. (Reutter et al. 2012) The fastest growing cities are forecasted to be Espoo, Munich, Vaasa, Berlin and Tampere. Since most of the cities have a clearly positive population forecasts, it can be assumed that the importance of these cities is growing and new energy infrastructure will be needed to fulfil the needs of their growing population.

Population densities affect energy consumption significantly (chapter 2.1). Therefore population densities of case cities were calculated by dividing population numbers by land areas (table 4.2). The German case cities have clearly bigger population densities than the Finnish case cities. Population densities also affect the choice of the most suitable energy production and distribution technologies. For sparsely populated cities, it can be assumed that there is more space to construct new plants but on the other hand, distribution is probably less efficient since distances are longer. In addition, average room density affects the need for heating energy.

4.3 Current energy consumption in the case cities

Published information about energy consumption in cities varies between the Finnish and the German case cities. Annual electricity consumptions of Finnish cities and towns are published by the Finnish Energy Industries, an industrial policy and labour market policy association. Electricity consumptions are presented divided into three categories: housing and agriculture, industry and service and building (table 4.5). The distribution of energy consumption varies a lot between the cities. For instance in Joensuu, industry is clearly the most energy consuming sector, whereas in Espoo industry has only a minor role. The distribution is relatively similar in Tampere Turku and Vaasa, where service and building account for the greatest share of energy consumption; energy consumption of the housing and agriculture sector is almost as high and industry accounts only for smaller share.

Energy consumption data from the German cities is taken from various sources, hence the values may not be accurately comparable. Because data on energy consumption in Wuppertal was not available, only values of the four other cities are compared (table 4.5). The values for Munich are from 2008 and the other values are from 2010. Population numbers are from 2011.

To compare the cities by their specific consumptions of energy, electricity and district heating consumptions are divided by number of inhabitants (table 4.5). The specific electricity consumptions of the Finnish case cities are in the range of 7.75-16.45 MWh/person whereas the electricity consumptions of the German cities are between 3.46 MWh/person and 6.2 MWh/person. Hence the electricity consumption per person is clearly bigger in the Finnish case cities. In district heating consumption, the difference is even more significant. However, district heating consumption is not very informative in relation to energy efficiency, since the coverage of district heating network is not similar in all cities. Length of district heating network also affects electricity consumption because alternative heating methods are usually electricity consuming.

Average annual degree days describe the need for heating energy in the cities based on differences in outdoor and indoor temperatures. Heat demand in different cities can be compared more accurately by using degree days. When annual degree days are calculated, the difference between average outdoor temperature of the day and 17°C, that is assumed to be average indoor temperature, is first calculated for each day. Secondly, degree days of the year are summed together. (Ilmatieteenlaitos) Long-term average annual degree days for the Finnish case cities are between 3878°days and 4984°days and for the German case cities between 2296°days and 2889°days (table 4.5).).Values for Espoo, Freiburg im Breisgau and Wuppertal were not available in the statistics, so the values from the closest available city were used. Because the Finnish cities have clearly higher values for degree days, the reason for higher energy consumption in the Finnish case cities seem to be explained by colder climate. However, also warm climate increases energy demand if energy must be used for cooling.

The total electricity consumption is approximately proportional to population in the Finnish cities; only Joensuu has a clearly higher consumption in relation to its population number. In Joensuu, the consumption of the industry sector is significantly higher than that of any other case cities, which explains the difference to the other Finnish case cities. The weighted average of electricity consumption is 8.93 MWh/person. District heating consumption per capita is the greatest in Vaasa (10.0 MWh/person) and the smallest in Joensuu (7.4 MWh/person).

According to table 4.5, Berlin has the lowest electricity consumption per capita of the German case cities and Hamburg has the highest. Instead, district heating consumption is the highest in Munich and the lowest in Hamburg. Sector “households” is clearly the biggest energy consumer in all other German cities except of Munich, where industry has the highest demand for energy.

Electricity and district heating consumptions are compared with population densities (tables 4.2 and 4.5), which was said to affect greatly energy consumption of cities. For example, Tampere and Freiburg im Breisgau have relatively equal population numbers, but population density is more than 3.5 times higher in Freiburg in Breisgau. Instead, electricity consumption per capita is 1.6 times higher in Tampere. Joensuu is clearly the city with the lowest population density and the highest electricity consumption per capita, and Berlin the city with the highest population density and the lowest electricity consumption per capita. Although the high electricity consumption per capita in Joensuu is mainly due to the exceptionally high consumption of the industry, population density seems to explain variations in electricity consumption per capita quite well in the other cases cities.

***Table 4.5.** Summary of annual energy consumption in the case cities (Barthel 2009; Kenkmann et al. 2012; Statistisches Amt für Hamburg und Schleswig-Holstein 2012; Energiateollisuus 2013a; Statistik Berlin Brandenburg 2013; Deutscher Wetterdienst (values applied); Ilmatieteenlaitos)*

Town	Distribution of final energy consumption			Electricity consumption (GWh)	District heating consumption (GWh)	Electricity consumption per capita (MWh/cap)	District heating consumption per capita (MWh/cap)	Degree days per year (°day)	Distribution of electricity consumption		
	Households (GWh)	Industry (GWh)	Traffic (GWh)						Housing and agriculture (GWh)	Industry (GWh)	Service and building (GWh)
Espoo	N/A	N/A	N/A	2 021	2 109	7.75	8.08	3 878	961	132	928
Joensuu	N/A	N/A	N/A	1 225	549	16.45	7.37	4 984	285	699	242
Tampere	N/A	N/A	N/A	1 791	2 073	8.12	9.40	4 424	665	344	783
Turku	N/A	N/A	N/A	1 560	1 748	8.56	9.59	4 021	582	254	723
Vaasa	N/A	N/A	N/A	585	665	8.82	10.02	4 469	216	150	218
Berlin	51 398	4 715	18 270	12 172	12 921	3.48	3.69	2 674	N/A	N/A	N/A
Freiburg im Breisgau	4 655	1 189	1 186	1 154	1 069	5.04	4.67	2 680	N/A	N/A	N/A
Hamburg	26 480	10 374	16 342	11 149	1 697	6.20	0.94	2 736	N/A	N/A	N/A
Munich	12 000	118 000	5 300	7 100	9 500	5.15	6.89	2 889	N/A	N/A	N/A
Wuppertal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2 296	N/A	N/A	N/A

4.4 Current energy infrastructure and production mix

To obtain a general view of the characteristics of the current energy systems in the case cities, existing energy infrastructure of the cities is described. The level of detail in the description depends on the amount of information available.

4.4.1 Overview of existing energy infrastructure

Almost all the biggest energy production units in the case cities are fossil fuel-fired (table 4.6). Joensuu is the only case city where the biggest power plants are fired with wood and peat. Especially the German cities have currently only minor bioenergy production that is mostly related to biogas production or energetic utilization of different waste fractions. In the Finnish cities, bioenergy production has also a rather important role in heat only production, and, measures for replacing fossil fuels with biomass have already been made e.g. in Vaasa where a biomass gasification unit integrated to the coal plant has been constructed. Turku, Vaasa, Berlin, Hamburg and Munich have waste incineration plants with significant capacities (capacity at least 100 MW).

The existing district heating and natural gas networks are important factors for decision making in energy-related issues. All the case cities have rather large district heating networks (table 4.6). Joensuu is the only Finnish case city where district heating does not cover at least 70% of homes. Numerical information of the district heating network of Freiburg im Breisgau was not available, but all the other German case cities have large networks. Espoo, Tampere and all the German case cities also have natural gas networks (table 4.6). A natural gas network can be used for biogas delivery and it is a prerequisite for the introduction of power-to-gas storage systems. An existing district heating network can be a determining factor when deciding on implementing low-carbon heating systems.

Table 4.6. *Overview of existing energy infrastructure in the case cities*

City	Main energy production technology	Role of bioenergy	District heating network (share of people living in connected apartments or length)	Natural gas network (yes/no)	Special characteristics
Espoo	Gas- and coal-based CHP production	Biogas production	72 %	yes	Only 50% of electricity produced in the city
Joensuu	Biofuel- and peat-based CHP production, bio oil production plant integrated to a CHP plant	Wood, biogas, black liquor and wood residues for CHP production	57 %	no	Strong role of bioenergy, bio oil production
Tampere	Gas-, peat and wood-based CHP production	Wood in CHP production, wood-based heating plant under planning and waste-based CHP plant under construction	86 %	yes	N/A
Turku	Coal-based CHP production	Biomass- and waste-based heat production, a new multi-fuel plant under planning	94 %	no	N/A
Vaasa	Coal-, biomass-, and waste-based CHP production	Waste-based CHP production, gasification of biomass for CHP production	80 %	no	N/A
Berlin	Coal-, gas- and biomass-based CHP production	Biomass- and waste-based CHP production, biogas production	1600 km	yes	One of the largest district heating networks in Europe, biogas injection into gas grid
Freiburg im Breisgau	Gas-based CHP production	Small-scale biomass-based CHP production	N/A	yes	Areas with decentralized low-carbon energy production
Hamburg	Gas- coal- and waste-based CHP production	Biogas production from solid waste and sewage	770 km	yes	Injection of biogas into gas grid
Munich	Gas-, coal- and waste-based CHP production	Two biogas production plants	800 km	yes	Pumped-storage hydro power plants, injection of biogas into gas grid
Wuppertal	Gas-, coal- and waste-based CHP production	Biogas-fired CHP plants	N/A	yes	N/A

4.4.2 Energy infrastructure in Espoo

The main energy production unit in Espoo is a coal and natural gas CHP plant with a capacity of 359 MW_e and 554 MW_{th} (Fortum 2014). Additionally, there are eight heating plants with a total capacity of 697 MW_{th}. All heating plants utilize either natural gas or oil as a fuel. (Raunio et al. 2012) At the landfill site in Ämmässuo, landfill gas is collected and combusted in a CHP plant with electrical capacity of 15 MW. The produced heat is used mainly in the landfill area. (HSY 2012) In 2014, construction of a new biogas plant started at the landfill site. The plant has the capacity to process 60 000 tonnes of biowaste. The product gas will be utilized in a gas engine plant with capacities of 1.8 MW_e and 1.8 MW_{th}. (HSY 2014)

District heating is clearly the main heating method both in Espoo and in the whole capital area. Electrical heating is the second most important method followed by oil and gas. 72 % of the population of Espoo lives in houses connected to the district heating network (Energiateollisuus 2013), and, in addition, there is a natural gas network in the area of the city. Power production in Espoo accounts for approximately half of the total consumption of the city. (Pääkaupunkiseudun ympäristötieto 2013)

4.4.3 Energy infrastructure in Joensuu

Joensuu has two hydro power plants with a total capacity of 4.8 MW_e. Furthermore, there is one CHP plant with electricity generating capacity of 45 MW and heating capacity of 130 MW. The main fuels are wood and peat; biogas is used as additional fuel. (Energiavirasto 2014). In 2013, a bio oil production plant started its operation integrated to the CHP plant. The process is based on fast pyrolysis technology and its feedstock is wood chips and other biomass. The annual production capacity of the bio oil plant is 50 000 tons of oil. (Fortum 2014) Another large-scale production unit is an industrial CHP plant with electric capacity of 105 MW connected to a pulp mill that produces black liquor and wood residues that are combusted in the CHP plant. In addition, there is one industrial CHP plant with electrical capacity of 2.8 MW which main fuel is wood residues. (Energiavirasto 2014) There are also 11 heating plants with a total capacity of 248 MW (Fortum 2014). 57% of the population of Joensuu lives in buildings that are connected to district heating network (Energiateollisuus 2013).

4.4.4 Energy infrastructure in Tampere

The municipal energy company of Tampere operates three CHP plants. The biggest one has a capacity of 147 MW of electricity and 160 MW of heat, and it was opened in 1988. The main fuel is natural gas. Another plant was modernized to use natural gas in 2000 and currently has a power production capacity of 129 MW and heat production capacity of 144 MW. The third plant was modernized in 1998 and it utilizes peat, wood, gas and oil as fuels. The electrical capacity of the plant is 60 MW and heating capacity is 120 MW. Furthermore, there are three hydro power plants with total capacity of 14.2 MW.

There are also 10 heating plants that are utilized for district heating. (Tampereen Sähkölaitos 2013)

The district heating network covers 86% of the whole population of Tampere (Energiateollisuus 2013). There is also a natural gas network with a total length of 50 km and nearly 100 connected buildings in the area of Tampere and the neighboring towns of Pirkkala and Ylöjärvi (Tampereen Sähkölaitos 2013).

Construction of a new waste-to-energy plant started in Tampere in 2013. The plant is based on grate technology, and should start operating in 2015. The capacity of the plant is approximately 150 000 tons of waste per year producing 100 GWh of electricity and 300 GWh of heat. (Tammervoima 2012) The main component of the waste fuel is non-recyclable communal waste that is collected from the Pirkanmaa region, that has currently approximately 420 000 inhabitants. The plant is also capable of receiving waste from outside of the region and industry. Slag and ashes from the grate will be utilized if possible by Pirkanmaan Jätehuolto Oy. (Aluehallintovirasto, Sisä- ja Länsi-Suomi 2013)

In February 2014, the municipal energy company of Tampere made an agreement on construction of a new 49.5 MW heating plant with an annual heat production ranging from 100 GWh to 400 GWh. 90% of the fuel is expected to be wood fuels, mainly wood chips, bark and sawdust and the rest is peat and light fuel oil. The heating plant is supposed to start operating in 2015. (Tampereen Sähkölaitos 2014)

4.4.5 Energy infrastructure in Turku

Turku has a waste incineration plant that processes approximately 50 000 tons of waste annually producing 100 GWh of heat for the district heating network. There is one main biomass heating plant and six smaller plants in Turku. The total capacity of the heating plants is 517 MW. (Turku Energia) The electricity of the region is produced mainly in Naantali in a coal CHP plant with an electrical capacity of 290 MW (Energiavirasto 2014). The district heating system covers the homes of 94 % of the city's population (Energiateollisuus 2013). The degree of self-sufficiency was 46 % in 2010 (Kuusiola et al. 2010).

A new multi-fuel plant is planned to start operating in Naantali in 2016 and replace the old coal-fired plant. The new plant is planned to be based on a circulating fluidized-bed boiler and to have capacities of 145 MW_e and 250 MW_{th}. Suitable fuels for the plant would be coal, various biomasses, peat and refinery gases. Also waste-derived fuels can be co-combusted with other fuels. (Aluehallintovirasto, Etelä-Suomi 2013)

In 2010, the production based primary energy consumption of Turku region was 12 400 GWh. Coal was the most important energy source with the share of more than 40 % of primary energy consumption, bioenergy had a share of 9 % and other renewable energy sources only 2 %. (Kuusiola et al. 2010)

4.4.6 Energy infrastructure in Vaasa

Vaasa has two CHP plants: one is fuelled with coal and has a capacity of 230 MW_e and a heating capacity 175 MW_{th} and the other is an oil-fired peak-load power plant with capacities of 160 MW_e and 175 $MW_{th.}$ In 2012, a new biomass gasification plant integrated to the coal power plant started operating. The aim is to replace 25-40 % of the coal with local biomass, mostly by wood chips. (Pohjolan Voima 2014)

Non-recyclable waste from households and industry are utilized in a waste incineration plant that is located outside the city border of Vaasa. Annual energy production of the plant is approximately 80 GWh of electricity and 280 GWh of heat. The municipal energy company of Vaasa distributes the energy produced at the plant, but the waste is collected in other municipalities than Vaasa. (Westenergy 2014)

In 2007, the biggest share of the 18.8 TWh of fuel consumed in the major power plants in the region Ostrobothnia was biofuels that accounted for 53% of the consumption. Consumed biofuels include mainly black liquor, energy wood and bark. 42% of the consumption was coal and 5% oil and gas. (Wasberg et al. 2012) The share of population of the city that lives in buildings connected to district heating network is 80% (Energiateollisuus 2013).

4.4.7 Energy infrastructure in Berlin

There are several CHP plants in the region of Berlin, the biggest ones being mostly coal-fired or gas-fired (table 4.7).

Table 4.7. *CHP plants in Berlin and the region (Bundesnetzagentur 2012)*

Name	Electrical capacity (MW)	Heating capacity (MW)	Main fuels
Klingenberg	164	1010	Brown coal, gas
Reuter	160	230	Coal
Lichterfelde	432	720	Gas
Rüdersdorf	35	235	Biomass
Adlershof	19	96	Gas
Schöneweide	9,6	36	Coal
Mitte	444	670	Gas, Light distilate oil
Moabit	140	240	Coal
Lichtenberg	34	224	Gas
Berlin-Neukölln	20	65	Biomass

The waste-to-energy plant of Ruhleben was modernized in 2008-2012. The plant is capable of processing about 500 000 tonnes of waste annually. 2.3 tonnes of high pressure steam can be produced by combusting 1 tonne of waste. The produced steam is transmitted to Reuter power plant, where it replaces other fuels such as coal in power and heat production. In Ruhleben, a new biogas plant also started operating in 2013. The plant processes approximately 60 000 tonnes of biowaste from households by fermentation producing biogas that is supplied into the gas grid after refinery. Production gas is utilized for example as a fuel for garbage trucks. (BSR 2014)

Berlin has one of the largest district heating systems in Europe. The total pipeline length of network owned by Vattenfall Europe is nearly 1600 km, and there are 15400 connection points. In addition, there are also smaller district heating network owners and operators. In 2005, 70.2 % of the total electricity consumption was generated in Berlin and 38.1 % of the power production was CHP production. (Suck et al. 2011) There is also a natural gas network operated by the NBB Netzgesellschaft Berlin-Brandenburg mbH & Co (GASAG 2014).

4.4.8 Energy infrastructure in Freiburg im Breisgau

In Freiburg im Breisgau, 40 % of the electricity demand is produced in a steam and gas CHP plant with a capacity of 60.1 MW_e. The annual production of the plant is approximately 400 GWh of electricity and 566 GWh heat. The heat is currently used as high temperature process heat, but the waste heat from the process is currently not utilized. Suggestions defined in the energy strategy for utilizing the waste heat include identification of potential buyers and examining the potential for extending the existing heat network or construction a new network. There is also a gas CHP plant that produces cooling in addition to heat and electricity with electrical capacity of 18 MW. (Bundesnetzagentur 2012)

Furthermore, there are areas, called Vauban and Rieselfeld, with decentralized energy production solutions relying on solar energy and small-scale CHP production. In Vauban, heat and power is produced in a 234 kW_e and 7000 kW_{th} plant that consists of a wood-fired boiler and two gas-fired boilers (Vauban 2013). Annual hydropower production in Freiburg im Breisgau is around 1.8 GWh and wind power production 12.9 GWh, the corresponding percentages of the total energy consumption of the city being 0.17% and 1.29%, respectively. Bioenergy production in Freiburg im Breisgau accounts for 1.6 % of the total electricity demand of the city and in total 5% of electricity consumption is produced with renewable energy sources. (Rexel 2013) The length of the natural gas network in the region Freiburg im Breisgau is more than 5600 km (RheinEnergie 2014).

4.4.9 Energy infrastructure in Hamburg

In Hamburg, the biggest CHP plant has a capacity of 321 MW of electricity and 814 MW of heat. The main fuels are coal and natural gas. Another CHP plant is a coal plant with an electrical capacity of 250 MW and a thermal capacity 423 MW. A new coal-fired CHP plant with capacities of 1654 MW_e and 420 MW_{th} will start operating in 2014. (Vattenfall 2014)

The municipal energy company has 25 solar energy units with a total capacity of 25 MW, three small CHP plants with a total electrical capacity of 1 MW and a heat capacity 10 MW and three wind power parks with a total capacity of 7.4 MW. (Hamburg Energie 2014) Hamburg has a natural gas network that is 7400 km long and a district heating network with the length of 770 km (Hamburger Senat 2011).

There are several waste incineration plants in Hamburg. In Borsigstraße, both municipal solid waste and biomass are combusted to produce 160 GWh of electricity and 730 GWh of heat annually, and in Rugenberger damm, 320 000 tonnes of municipal solid waste is combusted at a 24 MW_e and 146 MW_{th} waste incineration plant. (Vattenfall 2014) Yet another waste incineration plant called Stapelfeld processes around 350 000 tonnes of waste annually producing 80 GWh of electricity and 230 GWh of heat (EEW Energy from Waste Stapelfeld GmbH 2014). In Bützberg, 70 000 tonnes of biowaste are fermented into 2.5 million m^3 biogas that is refined into methane and distributed via natural gas network. The plant was opened in 2011, and is operated by the municipal waste management company Stadtreinigung Hamburg. (Schmidt 2011) Another biogas plant is Stellinger Moor where 20 000 tonnes of organic waste is converted into biogas and combusted in a 1 MW_e and 1 MW_{th} CHP plant. The plant started operating in 2006. In addition, 18 GWh of biogas is produced annually from sewage at the waste water treatment plant of Hamburg Wasser and supplied into the natural gas network. (Hamburg Energie 2014)

4.4.10 Energy infrastructure in Munich

Stadwerke München is the municipal energy company of the city of Munich. SWM operates three CHP plants, eight heating plants, two small-scale gas CHP plants and six hydropower plants including some pumped-storage plants in Munich. The CHP plants are either natural gas or coal-fired (table 4.8).

Table 4.8. *Capacities and main fuels of the biggest CHP plants in Munich (Stadtwerke München 2014)*

Name	Electrical capacity (MW)	Heating capacity (MW)	Main fuel	Year of construction
Freimann	160	100	Natural gas	1974
Nord	360	900	Coal, waste	1964
Süd	696	814	Natural gas	1969

In the CHP plant called Nord, the biggest share of electricity is produced with coal in one boiler, but two other boilers combust around 700 000 tonnes of waste annually. Additionally, SWM produces electricity by photovoltaic with solar panels on the roofs of several buildings. The length of the district heating network in Munich is about 800 km. Approximately 70% of the electricity production in Munich is combined with heat production. (Stadtwerke München 2014)

There are two biogas production plants in Munich, a smaller one in Hellabrunn Zoo and a bigger one in Eggertshofen. In the Hellabrunn Zoo, around 2000 tonnes of biowaste is formed annually. The biowaste is fermented into methane and transmitted to a CHP plant, where it is combusted. The capacity of the plant is 40 kW of electricity and 74 kW of heat. The generated electricity is supplied to the grid and the heat is used for the heating of the Zoo. SWM has also started a separate unit for production of methane from biogas in Eggertshofen in 2011. The produced methane is supplied to the natural gas network und utilized for example in a CHP plant. (Stadtwerke München 2014)

4.4.11 Energy infrastructure in Wuppertal

Wuppertal has a municipal company, Wuppertaler Stadtwerke – Energie & Wasser AG, that operates most of the city's energy infrastructure. One of the biggest energy production units in Wuppertal is a waste-to-energy plant. The total capacity of the plant is 40 MW of electricity and 30 MW of heat. The plant has been operating since 1976. (AWG 2014) Furthermore, there are two CHP power plants Barmen and Elberfeld. Barmen is a gas and steam turbine plant with the capacity of 75 MW of electricity and 80 MW of heat. The main fuel of Elberfeld is coal, and it has the capacity of 78 MW of electricity and 189 MW of heat. In addition, there is an oil-fuelled peak-load power plant with electrical capacity of 60 MW. (WSW 2014)

There is also renewable energy production in Wuppertal. By 2008, there were 610 solar thermal devices in Wuppertal with total annual heat production of 1708 MWh. The total installed hydro power capacity of Wuppertal is 1234.5 kW. The biggest bioenergy plants are two biogas-fired CHP plants in Kohlfurt and Buchenhofen with electrical capacities of 430 kW and 2 MW, respectively. In Buchenhofen, also waste food is fermented. Wuppertal has a high connection rate to the district heating and natural gas networks. There are two major district heating networks that are connected to each other and several smaller zone heating networks. (Brendel 2009)

5 THE ENERGY STRATEGIES OF THE CASE CITIES

In order to reveal the targets and plans of the case cities for future energy systems, energy related documents listed in chapter 4 are analyzed. Firstly, a general view of the scope of the documents is created by reviewing all the listed documents. Secondly, the most relevant documents are chosen for a more detailed analysis on the future of bioenergy.

5.1 Overview of the case cities' energy targets

Each of the cities has several documents, where targets, scenarios and guidelines the development of the energy systems are analyzed. Although the level of detail in the analyzed documents varies greatly between the cities, several common targets can be identified.

5.1.1 Overview of energy production targets

Most case cities have more detailed plans for heating systems than for power production. Heat must be produced relatively close to consumers whereas electricity can be economically transported for longer distances and imported from other countries. All the case cities state that they will continue using and extending the district heating networks in their area, since CHP production increases significantly the efficiency rate of centralized combustion plants. Other renewable heating solutions are supported mainly outside the district heating network. Promoted heating technologies are especially district heating, heat pumps, ground heat utilization and solar thermal devices. It must be noticed that implementation of heat pumps, ground heat systems and solar thermal collectors raises electricity demand.

The scope and specificity of the documents was noticed to vary between the cities which can be mainly explained by the fact that the level of decision power in energy issues in cities varies. In Tampere, Turku, Vaasa, Munich and Wuppertal, the energy company is owned by the city, hence in those cities municipal strategies can be assumed to be followed. Instead, in Espoo, Joensuu, Hamburg and Berlin, the main energy infrastructure in the city area is owned by private companies who have great decision power about the future of the energy system. In order to achieve powerful strategies, for instance the city council of Hamburg has made agreements with the local energy companies.

The cities that set numerical targets for renewable energy production have often higher targets than the national level (table 5.1). Some of the cities have defined the targets in a different way, e.g. Munich has chosen a strategy to produce a given amount of renewable energy in production units partly or totally owned by the municipal energy company, no matter if the production occurs within the city borders or not. Most of the cities have defined targets for 2020, but Tampere has only longer-term targets for 2040 in the latest energy strategy.

Table 5.1. *Targets of the case cities for production and consumption of renewable energy and energy saving (Anderson et al. 2007; Timpe et al. 2007; Brendel et al. 2009; Bayerische Staatsregierung 2011; City of Hamburg 2011; Kenkmann et al. 2011; Suck et al. 2011; Uitamo 2011; Wasberg et al. 2012; Bürgerschaft der freien und Hansestadt Hamburg 2013; Karg et al. 2013; Stadtwerke München 2013; City of Joensuu 2014; Pirkanmaan liitto 2014)*

City	Targets on renewable in energy production	Targets on energy consumption
Espoo	N/A	Electricity consumption stops increasing by 2030
Joensuu	In 2025: 90% of the total energy consumption covered with renewable energy production	Total energy consumption -25% by 2025 compared to 2007
Tampere (Pirkanmaa)	In 2040, 50% renewable energy in final energy consumption	Energy consumption is planned to be cut by 1 % annually until 2040.
Turku (Southwest Finland)	In 2020, 40% of energy production based on renewable sources. Sectoral targets: 50% in heating and cooling, 33% in electricity, 20% in transport	Total energy consumption is estimated to remain on the current level until 2020 and then to start decreasing
Vaasa (Ostrobothnia)	In 2020: percentage of renewable energy in heating 50%, in electricity 70% and in transport: 20% , in 2050 the percentage will be 100% in all sectors	Expected increase in final energy consumption mainly caused by the industry sector
Berlin	In 2020, 17,8% of total electricity production based on renewable sources, in heating sector 4,99% from renewable sources and 32,7% district heating	Targeted energy consumption reductions 2005-2020: 9.8% in total, 12.6% in electricity, 10.4% in heating and cooling, 6.9% in transport
Freiburg im Breisgau	In 2020, 12,1% of the electricity production based on renewable energy sources and 88% CHP production of which 15,5% from renewable sources, 17,6% of total final energy demand renewable energy	Targeted energy consumption reductions 2005-2020: 18.3% in total, 13.0% in electricity, 1.8% in heating and cooling, 18.2% in transport
Hamburg	N/A	Energy saving measures especially related to buildings and transport
Munich	In 2025, total power production of the municipal energy company equivalent to the total electricity demand of the city	Electricity consumption of the whole Federal state will stay on the current level despite increasing use of electricity demanding actions. In Munich and the surrounding area, potential for energy saving in 2010-2030: -18% in heating, -19% in electricity and -10% in fuels
Wuppertal	N/A	Several projects on energy saving

The renewable energy targets are in most cases derived from GHG reduction targets. Specific GHG reduction targets are set first and suggested measures for reaching the targets include increasing renewable energy production.

On average, the targets for renewable energy production that the cities have set for themselves are higher than the national or EU-level targets. This is to a great extend because one part of the selection criteria was that the case cities were supposed to be among the forerunner cities. In addition, in cases where the city does not have especially ambitious plans, the numerical targets are probably not published, instead approximate guide lines for development are described.

5.1.2 Overview of energy consumption targets

Energy saving is an effective method for reducing carbon dioxide emissions (Directive 2009/28/EC) and therefore energy saving and energy efficiency measures and targets are listed in many energy and climate strategies. Some documents include numerical targets, but since the development of population number and economic structure is difficult to predict, also the total energy demand may vary.

Factors that are expected to affect energy consumption in most of the strategies include improved energy efficiency especially in building insulation and energy production, improved technologies for example in transport vehicles and better functioning public transport systems as a result of advanced land-use planning. Many of the cities aim for setting an example for the private sector in energy issues by observing energy efficiency in their own current and new buildings stock, by considering energy efficiency as one of the determining factors for buying decisions and by introducing forerunner solutions. In cities, energy consumption of households accounts usually for a great share of the total energy consumption of the city. By sharing information about energy efficiency and energy saving, municipalities can affect the energy consumption of individuals.

Energy demand of industry is in many cases difficult to predict. In some cities, such as Freiburg im Breisgau, the energy consumption of the industry sector is almost totally caused by a single company. In those cases, improvements in one industrial process can cause great changes in the energy demand. In many of the strategies, encouraging private companies for investigating potential for energy recovery and usage of waste is listed as one of the measures for improving energy efficiency. In cities such as Joensuu, where industry accounts for a great share of energy consumption, changes in industrial sector such as closures of factories can affect the city's energy balance substantially.

The scope and specificity of energy saving targets of the case cities varies from numerical targets to general guidelines for development (table 5.1). Cities can mainly control the energy use of municipal actions, which is why so few cities have set accurate targets on the total energy consumption.

5.2 Strategies on energy production and consumption

All the case cities have published documents regarding their climate protection and energy plans. In addition, many of the cities have also created reports on the longer-term potential for reducing emissions and increasing energy production from renewable energy sources in co-operation with various research institutes and local actors in the energy sector. The specificity of strategies varies between the cities; in some cases numerical targets for several matters and in other cases only rough guidelines for development are presented. Percentual targets are based on national and EU-level targets as well as various agreements between the cities and other parties such as ministries or movements. Especially the smaller cities, for example Vaasa, have drawn up strategies for the whole province instead of just the city itself.

5.2.1 The energy strategies of Espoo

In 2012, the city of Espoo had a report on renewable energy done by Motiva, WSP Finland and Fortum Power and Heat. The aim of the report was to clarify the current state of energy production and consumption and the potential for increasing local renewable energy production (table 5.2).

Table 5.2. *Potentials for different forms of renewable energy in Espoo (Raunio et al. 2012)*

Energy source	Heat (GWh/a)	Electricity (GWh/a)	Primary energy demand (GWh/a)
Biomass, CHP, replacement of coal and gas	1948	974	3438
Biofuels, heating plants, replacement of gas	257	0	286
Individual biomass heating solutions	629	0	786
Ground heat	629	-180	450
Heat recovery from waste water	350	-120	120-300
Solar energy	150	415-620	N/A
Wind power	0	100	N/A

Espoo aims for a 39% reduction of GHG emissions by 2030, and by increasing the share of renewable energy sources in energy production mix emissions can be significantly lowered. The report reveals that the greatest potential lies in replacing coal and gas by biomass at the Suomenoja CHP plant. After the switch, 1948 GWh/a of heat and 974 GWh/a of electricity would be produced by combustion of biomass. By replacing gas in heating stations, 257 GWh/a of heat would become biomass-based. Outside the district heating network, biomass could be utilized in individual heating solutions and thus increasing biomass based heat production by 629 GWh/a. By introduction of ground heat outside the district heating network, additionally 629 GWh/a of heat would be from renewable energy sources, but at the same time demand for electricity would increase by 180 GWh/a, assuming COP being 3.5. Solar energy could be utilized by installing solar panels on the roofs of existing buildings resulting to heat production of about 150 GWh/a and electricity production of about 415-620 GWh/a. According to a wind power report from 2010, Espoo has an area of 4-6 km^2 that would be suitable for a wind power park with annual electricity production of 100 GWh/a. By utilizing heat from waste water, 350 GWh/a of heat could be produced, but the recovery would require 120 GWh of electricity. (Raunio et al. 2012)

Espoo has an atypical energy system compared to other Finnish cities, since industry accounts only for 7% of the total energy consumption and there is no significant process heat production. The conclusion of the report is that the most techno-economically favourable ways to increase energy production from renewable sources are CHP production from biofuels, production of district heating with heat recovery or low-temperature heat sources and electricity for renewable energy sources. Outside the district heating network, utilization of heat pumps, bioenergy and solar energy are efficient heating solutions. Implementation of smart and integrated energy systems improve the potential for modern solutions. (Raunio et al. 2012)

The common climate strategy of the capital region of Finland was established in 2007. The core target of the strategy was to cut GHG emissions in the region by 39% compared to the level of 1990 by 2030. Major plans regarding energy systems include efficient utilization of CHP production. District heating and cooling will be further promoted. Production of district cooling can occur at CHP plants in the summer and also cold water from the sea and cleaned waste water can be utilized. By using return water from district heating systems for district cooling or for low-temperature heating for low-energy buildings, the efficiency rates of CHP production can be improved. District heating networks will be extended and barriers for extensions will be removed if possible. Outside the district heating network, renewable and low-emission heating solutions, especially heat pumps, ground heat and solar energy devices, will be promoted. Distributed energy production will be further developed to offer more ecological solutions. (Anderson et al. 2007)

In centralized energy production, waste incineration and utilization of gas are expected to grow according to the strategy. Cleaner technologies for utilization of coal and gas will be investigated and coal and gas will be partly replaced by waste-based fuels and renewable energy production. Potential of renewable energy sources, such as offshore wind power, will be investigated. Energy production based on renewable energy sources will be supported by favorable land-use planning and building regulations. (Anderson et al. 2007)

In the capital area, around 200 GWh of landfill gas was utilized in 2007, which contributed to a 1% GHG reduction. In addition, 50-60 GWh of biogas from sludge from waste water treatment plants was used. By further energetic utilization of mixed waste, 1-2% of total emissions of the area could be avoided. (Anderson et al. 2007)

It is estimated that the total kilometers driven in the capital area will be increased by 45% in 2005-2030. The basic target is to reduce the need for traffic and to promote public transportation and bicycle and pedestrian traffic. Vehicles and stations for public transport will be modernized and kept in good condition. Connections will be improved and costs reduced compared to private cars. The network of bicycle routes will be extended and improved and user-friendly and safe parking spots for bicycles will be developed. Low-emission vehicles and biofuels will be favoured especially in municipal traffic. The city structure should be extended taking into account the rail traffic connections. Rail traffic will be improved and new areas will be constructed in areas with easy access to rail traffic stations. (Anderson et al. 2007)

In the reference scenario of climate strategy of the capital region, it is estimated that electricity consumption will increase despite tightening energy efficiency standards for buildings. Before 2007, electricity consumption per capita had been growing approximately by 1% annually. (Anderson et al. 2007)

It is argued that the municipalities have limited possibilities to affect electricity consumption in other sectors than municipal services. However, by developing forerunner solutions and spreading the knowledge to private sector, total energy efficiency can be improved. Also by informing local citizens and companies and by considering energy efficiency in procurement sector, municipalities can contribute to electricity saving. In construction, energy efficiency must be observed already in planning phase. (Anderson et al. 2007)

Contrary to electricity consumption, municipalities have rather good possibilities to affect heat consumption, since municipal authorities are always contacted in relation to construction projects. Municipalities can give advice on energetic issues and act as an example and forerunner in energy efficient construction. (Anderson et al. 2007)

It is stated that the capital area resembles more North-American cities than other European cities in land-use because of sparse urban structure. Long distances increase annual traffic kilometers and as a result fuel consumption and emissions. By unifying and supplementing the urban structure fuel consumption could decrease, public transport system become more popular and district heating systems more efficient. (Anderson et al. 2007)

5.2.2 The energy strategies of Joensuu

In the "Climate program" of Joensuu from 2013, a target of having 90 % of final energy consumption produced from renewable energy sources in 2025 is set. A comprehensive report on potential for energy production from different renewable sources has not been made yet. The city aims at increasing the usage of especially solar, wind and wood energy and also ground heat and heat pump solutions when constructing or renovating buildings. It is stated that waste incineration is not solely a positive option in the sense of climate protection, but separate collection of energy waste will be promoted and the volumes of energy waste are expected to grow. (City of Joensuu 2014)

According to the "Climate program", oil-fuelled heating boilers will be replaced by wood chop or pellet boilers at the latest at the end of the life cycle of the old boilers. Use of peat will be decreased at power plants if possible and replaced by biofuels. The origin of imported electricity must be guaranteed and renewable energy should be favoured. In addition, Joensuu aims at becoming a carbon-neutral city by 2025. (City of Joensuu 2014)

The "Climate strategy" of the region Joensuu contains similar targets as the "Climate program" of Joensuu. Renewable energy production is targeted to be increased in all municipalities participating in the strategy and also energy producers are aimed to be involved in the target. The municipalities should support installation of new wind power production capacity as well as solar energy. Separate collection of biowaste will be increased and the municipalities should be positive about possible biogas production. (Joensuun seutu, Seutuhallinto 2009)

In 2005, 76% of all transport kilometers in Joensuu region were driven with private cars. The share of bicycle and pedestrian traffic was 13% and the share of public transport was 7%. By 2015, the municipal transport and need for private cars should be cut by 10%. Implementation of biogas as a fuel for traffic can be beneficial, since the biomaterial resources of the region are generous. Therefore the use of biogas will be promoted when it is techno-economically reasonable. The share of biogas and electrical vehicles is aimed to be 10% of the total car pool in 2020. (Joensuun seutu, Seutuhallinto 2009)

In the climate strategy of Joensuu region, the energy saving and energy efficiency targets are stated to be described in the energy efficiency program for municipalities by the Ministry of Employment and the Economy. One of the key actions in Joensuu is to improve the energy efficiency of municipal buildings. Significant savings should also be reached via optimization and modernization of street lighting systems. Energy consumption of municipal actions should be cut by 16% by 2016 compared to 2005. (Joensuun seutu, Seutuhallinto 2009) Overall energy consumption is targeted to decrease by at least 25% compared to the level of 2007 by 2025 (City of Joensuu 2014).

5.2.3 The energy strategies of Tampere

The climate and energy strategy of Pirkanmaa published in 2014 contains estimates on the distribution of energy sources in total energy mix based on the target of having 50% renewable energy in the final energy production mix in 2014 (table 5.3).

Table 5.3. *Mix of energy sources in final energy consumption in Pirkanmaa in 2011 and a target-based estimate for 2040 (Pirkanmaan liitto 2014)*

	2011 (GWh)	Vision for 2040 (GWh)	Change 2011-2040 (GWh)	Change 2011-2040 (%)
Gas	6 006	3 500	-2 506	-42
Oil	5 728	1 900	-3 828	-67
Coal	57	0	-57	-100
Peat	1 281	550	-731	-57
Imports	3 362	1 600	-1 762	-52
Recycled fuels	0	800	800	N/A
Wood and other biomass	3 175	4 600	1 425	45
Hydro	487	550	63	13
Wind	1	500	499	49 900
Solar	0	400	400	N/A
Other (Ground heat and hydrogen)	237	600	363	153
Total	20 334	15 000	-5 334	-26

Reductions are expected especially in gas and oil usage and imports, whereas the utilization of recycled fuels and biomass is growing. The increased usage of wood and other biomass is planned to occur by more efficient use of existing products and developing new means of utilization such as synthetic biogas, bio oil and bio coal. Biofuels will be used mainly in power plants, industry and decentralized energy production. (Pirkanmaan liitto 2014)

Recycled fuels include waste, sludge and industrial by-products. The new waste incineration plant will contribute to the increasing usage of recycled fuels. Another method will be biogas production from waste, sludge, manure and industrial by-products. Biogas will be used as substituent of natural gas and also as a transport fuel. Decentralized production will be promoted in various applications such as in housing companies, detached houses, recreational dwellings and small heating plants. Potential of agricultural biomass will be examined. (Pirkanmaan liitto 2014)

In the climate and energy strategy of Pirkanmaa, an annual energy saving of 1% in 2014-2040 is set as a target. As a result of the annual saving, total energy consumption of the region would be 26% smaller in 2040 than in 2011, when the total energy consumption was 20 087 GWh. (Pirkanmaan liitto 2014)

Key areas for energy saving measures are procurement, housing and construction, traffic and mobility, waste and recycling and education and consulting, but not industry. Old buildings are planned to be energetic renovated in liaison with other reconstruction and new buildings will be constructed according to energy efficiency standards. GHG emission reduction in the transport sector will be implemented through improved public transportation and dense urban structure. Composition of waste will be decreased, recycling promoted and the remaining waste will be utilized in energy production. Effective utilization of waste and by-production especially in industrial processes are promoted. With the help of education and consulting, knowledge of energy efficiency and low-emission actions citizens, companies and organizations is targeted to be improved. (Pirkanmaan liitto 2014)

5.2.4 The energy strategies of Turku

Targets for energy production in 2020 are defined in the energy strategy of the region Southwest Finland. In 2020, 40% of the energy production should be based on renewable energy sources. In production of heat and cool the share of renewable energy sources should be at least 50%, in power production 33% and in transport 20%. Local energy sources should be exploited as efficiently as possible. The use of wood chips will be doubled, wind power production will be at least 0.6 TWh/a and at least 0.8 TWh/a of heat will by produced by heat pumps. Active and passive solar energy will be utilized in all new building and also in reconstructed building when possible. Potential of small-scale distributed CHP production will be investigated. By 2030, Southwest Finland aims at being a carbon neutral province, as laid out both in province plan and environmental program (Uitamo 2011)

In the climate strategy of the region Southwest Finland, five scenarios for 2020 are described. In the reference scenario, two heat pumps with total heat capacity of 24 MW and one biomass-based heating plant with heating capacity of 40 MW have been introduced. One of the coal units in Naantali power plant will be replaced by other production of Turku Energia. In addition, it is assumed that bioenergy production will be increased also in other district heating networks in Southwest Finland. Waste heat recovery has been tripled in companies. Utilization of woodchips is estimated to be 600 GWh/a and the total usage of wood fuels to be 1500 GWh/a. Energy production from peat would be 290 GWh/a and production from recycled fuels would remain on the current level. Utilization of biogas is expected to be tripled in heating and CHP plants and also wind power production will grow by almost 600 GWh. Targets related to waste management include collection and utilization of landfill gas in old landfill sites. (Vieno 2011)

In the target scenario, 40 % of energy is produced from renewable sources and total energy production, especially power production, will be slightly decreased (table 5.4). (Vieno 2011)

Table 5.4. *Renewable energy production mix in region Southwest Finland in target scenario in 2020 (Vieno 2011)*

	Energy production in 2020 (GWh)
Wind	600
Wood chips	2000
Other wood fuels	1200
Other bioenergy (biogas, biowaste, field bioenergy)	1800
Peat	370

The coal CHP plant in Naantali is assumed to be closed. Instead, 600 GWh of process heat will be produced annually with woodchips and peat. Utilization of oil will be partly replaced by renewable energy solutions. Also industrial utilization of coal will be reduced and partly replaced by wood pellets and other renewable fuels. (Vieno 2011)

The municipal energy company of Turku, Turku Energia, has published a list of key elements of its strategy for 2013-2016 and a vision for 2020 on its webpage. According to the listing, Turku Energia plans to invest to new renewable and low-carbon production capacity by 2020. Planned investments include a new multi-fuel plant in Naantali and possibly a new regional waste incineration plant. Potential for solar energy in district heating areas and technical and economic possibilities of using renewable fuels for backup power are being investigated. By 2020, Turku Energia aims for having the self-sufficiency rate of 50% in environmental friendly energy production. (Turku Energia 2012)

According to the vision of the energy strategy of Southwest Finland, total energy consumption of the region would stay on the same level as in 2007, although energy demand of the industrial sector will increase and demand for cooling will grow. After 2020, total energy consumption of the region is assumed to start decreasing. (Uitamo 2011)

In the reference scenario of the climate strategy of Southwest Finland, demand for heating energy is assumed to stay on the current level and demand for electricity will possibly be slightly reduced as a result of a decrease in usage of electrical heating. Traffic volume is expected to grow by 17 % but due to improved technologies, increase in demand for traffic fuels will be only 10 %. Energy consumption is not defined separately for the target scenario. (Vieno 2011)

Land-use planning should support energy saving by planning work places and services to be easily reachable and close to housing areas if possible. New construction and new housing areas will be planned near railway stations. Instructions and best practices for energy efficient construction are collected and placed easily available for builders.

Municipalities and other public corporations act as forerunners in energy efficient construction. (Vieno 2011)

5.2.5 The energy strategies of Vaasa

According to the Ostrobothnia Region's climate strategy, clearly the biggest growing potential of renewably energy sources is in wind power. In 2008, only 0.013 TWh was produced by wind power, while the potential would be 5-8 TWh. It is estimated that the installed wind power capacity of the Ostrobothnia region would be around 1500-1800 MW in 2030. Also the utilization of wood, straw, ground heat, biowaste and sludge has potential to grow. The annual forest growth in Ostrobothnia region is equivalent to 4.2 TWh. (Wasberg et al. 2012)

Next to district heating, also other heating methods will be introduced. Heat pumps and ground heat systems will grow in number and heat recovery from various sources will become more common. Gasification of landfill waste will be increased and product gas will be used for power production and transport. In 2040, Ostrobothnia is striving for having 100% of energy consumption produced from renewable sources in all sectors heating, power production and transport. For 2020, targets for the sectors are 50%, 70% and 20%, respectively. (Wasberg et al. 2012)

It is expected that there will be major changes in the transport sector during the planning period until 2040. In 2008, transport was solely based on fossil fuels. In the future, biogas, bio diesel, fuel cells and especially electric vehicles are supposed to grow in number rather rapidly. Increasing number of electric vehicles and growing wind power production can support each other since the batteries of plug-in vehicles can balance the unstable power production of wind turbines. (Wasberg et al. 2012)

One third of the total wind power potential in Finland is in Ostrobothnia region. One of the main targets of Vaasa is to become a leading area for wind power production and therefore wind power will be promoted in many ways. Research on biodiesel aims to establish a biodiesel plant in Ostrobothnia. In addition, smart grids will be developed and demonstrated. (Wasberg et al. 2012)

The energy strategy of the region Ostrobothnia contains estimations about the development of consumption of different energy forms by 2020 (table 5.5). Industry sector accounted for 55 % of total electricity consumption in 2008 and industry is expected to still increase its energy consumption by 1600 GWh/a by 2020. Greenhouse cultivation, which is an important trade for the region, should cut energy consumption by 30 % and half of the farms should utilize renewable energy in 2020. (Wasberg et al. 2012)

Table 5.5. *Consumption of different forms of energy in Ostrobothnia in 2008 and 2020 (Wasberg et al. 2012)*

	2008 (GWh/a)	2020 (GWh/a)	Change 2008-2020 (GWh/a)
Heating (excluding electrical heating)	2 500	3 000	500
Greenhouse cultivation	700	500	-200
Electricity	3 500	5 500	2 000
Transport	1 500	1 000	-500
Total	8 200	10 000	1 800

Table 5.5 shows that the final energy consumption is about to increase by more than 20 % to 10 000 GWh/a. The greatest increase will occur in demand for electricity mostly due to greater energy demand of industry sector. Instead, in the transport sector and greenhouse cultivation energy consumption is decreasing. (Wasberg et al. 2012)

5.2.6 The energy strategies of Berlin

In 2005, renewable energies accounted for 1.2 % of the total energy consumption in Berlin, whereas in 2020 the share should be 17.8 % if the targets defined in energy concept will be reached. The potential renewable energy sources are photovoltaic, wind power and biomass. Especially biomass-based energy production is planned to be increased significantly both in reference and target scenarios (figure 5.1). (Suck et al. 2011)

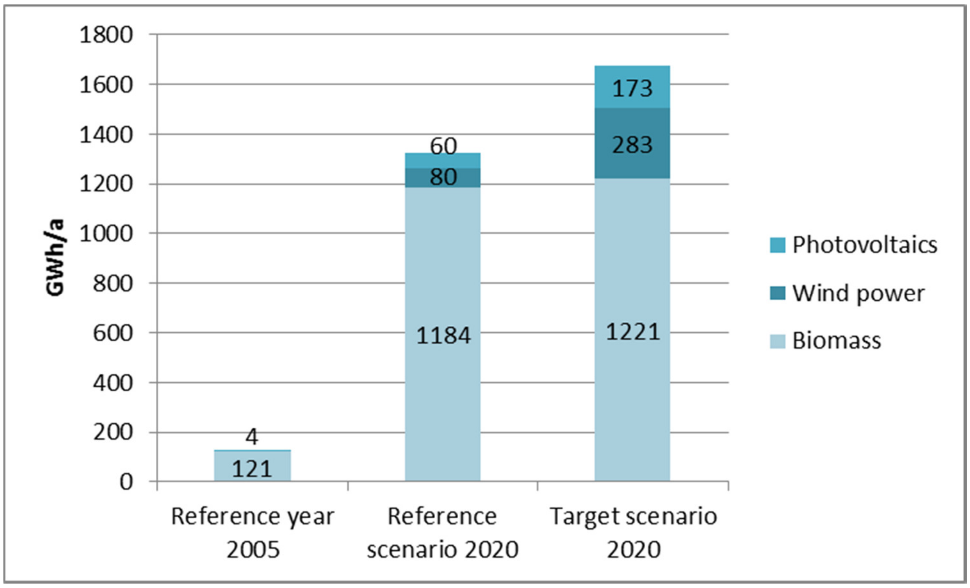

Figure 5.1. *Energy production from renewable sources in Berlin in 2005 and in 2020 according to different scenarios (Suck et al. 2011)*

The planned increase in biomass production is 1 063 GWh/a in the reference scenario and 1 100 GWh/a in the target scenario. Two biomass power plants are planned to be constructed with electrical capacity of 40 MW and thermal capacity of 150 MW. The coal CHP plant Lichterfeld will be replaced by a gas and steam power plant with capacities of 300 MW_e and 230 MW_{th}. Co-combustion of biomass is also planned for several coal CHP plants. (Suck et al. 2011)

Targets for renewable energy production in 2020 are defined separately for the heating sector (figure 5.2). Heat production from renewable energy sources is estimated to be multiplied if the targets of the "Energy concept 2020" will be reached. Biomass-based heat production is calculated to grow by 1500 %, CHP production by 800 % and solar energy by 1700 %. In 2020, biomass would be clearly the most important renewable energy source for heat production. (Suck et al. 2011)

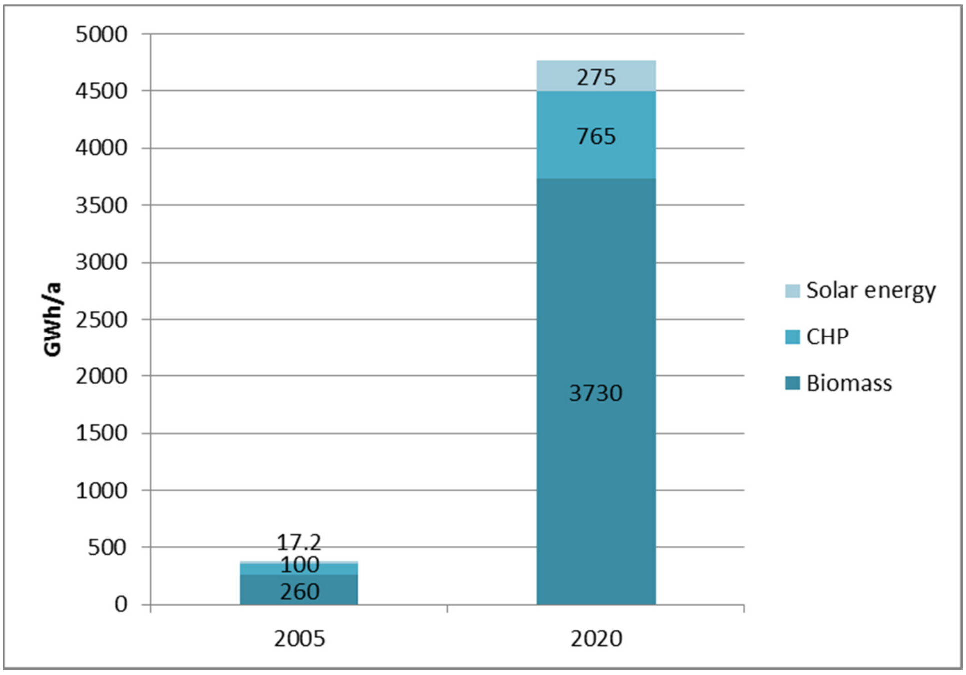

Figure 5.2. *Annual heat production from renewable energy sources in Berlin in 2005 and in 2020 (Suck et al. 2011)*

When investigating the potential for introduction of various renewable energy technology solutions, land areas in both Berlin and an area of 16000 ha in the neighboring state Brandenburg is observed. Majority of the biomass and also biogas and bio methane must be imported to Berlin from other areas. In the neighbouring state of Brandenburg, several biogas plants are planned to be constructed by 2015. (Suck et al. 2011)

In both target and reference scenarios, it is assumed that the annual modernization rate of heating devices is 5%. The share of renewable energy solutions in new construction is expected to be 75 % in detached houses and 50% in multiple dwellings. In other buildings than dwellings, the share of renewable heating solutions in new construction is assumed to be 40%. (Suck et al. 2011)

Especially pellet boilers and wood gasification boilers are expected to become more common in detached houses, and wood chip devices in multiple dwellings and other buildings. The share of district heating in distribution of heating forms in private households is targeted to be risen by 4 % and the share of natural gas by 3.7 %. The greatest absolute growth in heat production with individual heating devices in 2008-2020 is targeted to occur in heat pumps and biomass production (table 5.6). (Suck et al. 2011)

Table 5.6. *Individual heating systems in Berlin in 2008 and target scenario for 2020 (Suck et al. 2011)*

	2008 (GWh)	Target scenario 2020 (GWh)	Change 2008-2020 (GWh)	Change 2008-2020 (%)
Solar thermal	19	275	256	1 347
Biomass	9	647	638	7 089
Heat pumps	49	730	681	1 390
Total	77	1 652	1 575	2 045

In 2008 there were approximately 260 decentralized CHP units with total electrical capacity of 15 MW. It is estimated that the total number of decentralized CHP devices in Berlin in 2020 could be 2175 with total capacity of 63.7 MW. (Suck et al. 2011)

In the "Energy Concept 2020" for Berlin, the development of the energy consumption of the traffic sector is analyzed with two different scenarios. In the reference year 2005, the total consumption was 18 428 GWh. In the reference scenario, the energy consumption would decrease by 5% due to energy efficiency measures of traffic companies caused by increasing energy prices and changes in traffic agreements. In the target scenario the decrease in energy consumption of the transport sectors is 6.9% denoting the total energy consumption of 17 155 GWh in traffic in 2020. Energy consumption scenarios are drawn up for four different sectors of traffic: shipping, air traffic, rail traffic and road traffic (table 5.7). It can be seen that in both scenarios the energy consumption of road traffic is decreasing. On the contrary, the energy consumption of shipping and air traffic are increasing in both scenarios. The energy consumption of rail traffic decreases in reference scenario but increases in target scenario. (Suck et al. 2011)

Table 5.7. *Energy consumption of the traffic sector in Berlin in 2005 and in two scenarios for 2020 (Suck et al. 2011)*

Traffic form	Reference year 2005 (GWh)	Reference scenario 2020 (GWh)	Target scenario 2020 (GWh)
Shipping	126	139	145
Air traffic	3 321	4 815	4 815
Road traffic	14 141	12 020	11 313
Rail traffic	840	798	882
Total	18 428	17 772	17 155

The decrease of energy consumption in road traffic is planned to occur via more energy efficient technology, land-use planning and environmental-friendlier vehicle choices. Alternative fuels are not expected to have a significant impact. Measures for reducing the overall energy consumption in traffic include promotion of bicycle and pedestrian traffic, development of public transport, and measures in traffic management. (Suck et al. 2011)

It is stated in the Energy concept of Berlin that to reach the desired CO_2 emission reductions (40% by 2020), a 10% decrease in final energy consumption is needed. According to the target scenario, the final energy consumption in 2020 would be 62 596 GWh. Targeted final energy consumption in 2020 is defined separately for different sectors (figure 5.3). The most significant change is expected for the heating sector where energy consumption per year should decrease by more than 4 000 GWh. (Suck et al. 2011)

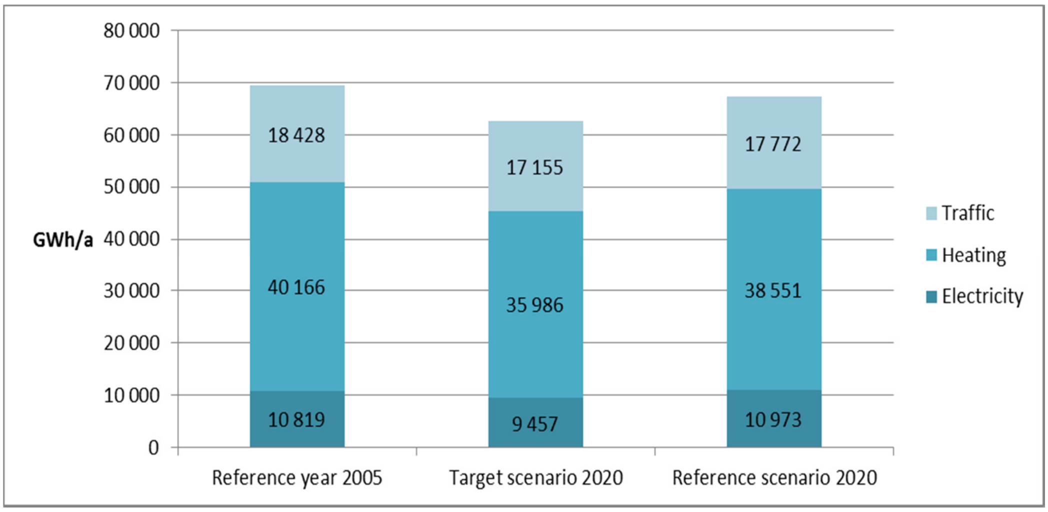

Figure 5.3. *Final energy consumption by sector in Berlin in 2005 and target scenario for 2020 (Suck et al. 2011)*

5.2.7 The energy strategies of Freiburg im Breisgau

The city of Freiburg has set a target of reducing CO_2 emissions by at least 40% by 2030. The climate protection target guides also the development of the energy system. In the climate protection strategy of Freiburg from 2007, four alternative development scenarios and an action plan are presented. In the basic scenario, it is assumed that the current climate protection measures will not be continued and new actions will not be adopted. Reference scenario describes the effects of adopted measures without significant further actions. The third scenario is called "Focus City" and it describes the effects of ambitions actions of the private and commercial actors in the city. The scenario "Optimal climate protection environment" contains even more positive development of climate protection assuming that also national and EU-level targets will be set higher. The most plausible scenarios are reference scenario and "Focus City" and therefore these two scenarios are analyzed further. (Timpe et al. 2007)

In the scenario “Focus City”, CHP production will be moderately increased. The biggest share of the growth is expected to occur via renovations of old buildings, new construction accounts only for a smaller share. It is assumed that in master plan areas 25% of new dwellings will be supplied by CHP production. It is mentioned that construction of new regional heat networks may not be economic in areas with high heat saving standards. (Timpe et al. 2007)

Biogas is assumed to partly replace natural gas in some of the centralized CHP plants. Biogas is planned to be produced outside the of city borders and distributed via natural gas network. Biogas potential of the surrounding region will be exploited but also imports from other regions may be needed. (Timpe et al. 2007)

Annual power production from renewable energy sources is estimated both in the reference scenario and in the scenario “Focus City” for the years 2020 and 2030 (table 5.8). In both scenarios, hydro power production will be increased by 47.4% and photovoltaic by 200% in 2005-2030. The only significant change is in bioenergy production. The increase in bioenergy production is only 7.8% in the reference scenario but with additional promotion measures in the “Focus city”, the growth can be 21.0%. (Timpe et al. 2007)

Table 5.8. *Power production from renewable energy sources in Freiburg im Breisgau in reference scenario and in the scenario “Focus city” (Timpe et al. 2007)*

	2005 (GWh)	Focus City 2020 (GWh)	Focus City 2030 (GWh)	Change Focus city 2005-2030 (%)	Reference scenario 2020 (GWh)	Reference scenario 2030 (GWh)	Change Reference scenario 2005-2030 (%)
Bioenergy	6.4	55.4	103	1509.4	7.8	7.8	21.9
Hydro power	1.9	2.8	2.8	47.4	2.8	2.8	47.4
Landfill gas	10.2	0.8	0	-100.0	0	0	-100.0
Photovoltaic	6	12	18	200.0	14	18	200.0
Wind power	13.8	13.8	13.8	0.0	13.8	13.8	0.0
Total	38.3	84.8	137.6	259.3	38.4	42.4	10.7
Share of electricity demand of the city	3.7 %	8.3 %	14.6 %	N/A	3.7 %	3.9 %	N/A

The action plan of the climate protection strategy contains for instance plans for model projects of renewable energy systems. Some of the projects are already in progress, such as installations of solar energy panels on municipal buildings and wood-based heating systems in schools and decentralized CHP plants. There are plans for further projects as well, for example for more photovoltaic installations. District heating is promoted by obligating buildings in areas of Rieselfeld and Vauban to be connected to the local district heating network. Exceptions can be allowed to passive houses and houses with individual wood pellet heating systems. Similar regulations are planned for new areas as well to ensure sufficient connection density to make district heating production economic. (Timpe et al. 2007)

In the document “Freiburg 2050 – Auf dem Weg zur Klimaneutralität”, a climate strategy for Freiburg im Breisgau for a longer period is described. The core target of the strategy is a reduction of CO_2 emissions by at least 90% by 2050. The document is from 2011 and unlike the climate protection strategy, written after the new energy policies of the state and therefore it is analyzed parallel to the official climate protection strategy. (Kenkmann et al. 2011)

The development of total power production in the city area from renewable energy sources is calculated for both reference and target scenarios. The fastest growing power production technology is wind power in both of the scenarios. The estimated production amounts for wind power are much higher than in the climate protection plan that was drawn up four years earlier. (Kenkmann et al. 2011)

The energy strategy contains estimates on fuel consumption for power and heat production in the city area in the target and reference scenarios. In both the scenarios, the usage of coal will be ended until 2020. Also the utilization of natural gas decreases, in the target scenario by more than 40 % by 2030. Instead, solid biomass, biogas and natural biogas will grow in importance. In the target scenario, the total increase in utilization of biofuels (solid biomass, biogas and natural biogas) is 510.1 GWh/a by 2030 (table 5.9). (Kenkmann et al. 2011)

Table 5.9. *Target scenario for fuel consumption in power and heat production in the city area of Freiburg im Breisgau in 2010-2030 (Kenkmann et al. 2011)*

Fuel	2010 (GWh/a)	2020 (GWh/a)	2030 (GWh/a)	Change 2010-2030 (%)
Biogas	27.3	57.1	71.4	161.5
Coal	64.8	0.0	0.0	-100.0
Heating oil	2.0	1.7	1.1	-45.0
Landfill gas	2.0	1.3	0.9	-55.0
Natural biogas	13.1	31.4	54.3	314.5
Natural gas	1729.7	1508.1	1005.4	-41.9
Solid biomass	44.0	189.6	468.8	965.5

Heat production is planned to be mainly based on centralized production. The usage of biofuels depends highly on the availability and price of solid and gaseous biomass. In the target scenario, solid biomass will grow significantly in importance in CHP production. Also a great amount of wind power and photovoltaic capacity will be constructed in the city area. Local renewable power production in 2050 could cover 75 % of the electricity consumption of the city. (Kenkmann et al. 2011)

In the target scenario, all district heating production is based on renewable energy sources, but the alternative scenarios include solar energy, centralized heat pumps, biomass, geothermal energy and possible modern technologies that are still unknown. Nevertheless, in the target scenario, the centralized heat production is assumed to occur via combustion of biomass. The current CHP plants Uni-Klinik and Rhodia that will still be operating in 2050 are supposed to be solid biomass-fired and the smaller CHP plants are supposed to be biogas and partly solid biomass-fired. (Kenkmann et al. 2011)

The report “Freiburg 2050 – Auf dem Weg zur Klimaneutralität” contains recommendations of actions for heating systems. According to the study, demand for heat of various areas of the city should be analyzed and the most suitable heating system should be chosen. District heating is recommended to be promoted in dense areas, where energetic renovation is not possible or where heating demand will remain high also after renovation. District heating must be produced solely from renewable energy sources. New concepts of district heating, such as so called low-temperature district heating, can be economic in areas with low demand for heating. (Kenkmann et al. 2011)

In the report, potential for utilization of various renewable energy sources is estimated. It is stated that there is 6400 ha of forest in the city area of Freiburg. Approximately 6000 tonnes of waste wood from this area can be utilized in energy production which is equivalent to 25.2 GWh/a of primary energy. The maximal power production capacity from biomass could be 39 GWh/a in 2030. The biomass-based energy production would occur in Uni power plant after conversion of combustion technology and in centralized and decentralized heating plants. (Kenkmann et al. 2011)

In 1995, the total roof area suitable for solar energy production in the city of Freiburg was 2 million m^2. 1.5 million m^2 of the total area is located outside of the district heating network and is therefore suitable for solar thermal production. The total potential for electricity production in the roof areas is 335 GWh/a with radiation of 1000 kWh/m^2 and efficiency rate of 15%. (Kenkmann et al. 2011)

Wind power capacity of the city is not yet fully investigated, but the report from 2011 estimates the wind power production to be 57 GWh/a in 2030. Hydro power potential is already fully exploited, but the report from 2011 estimates that hydro power production could be increased by more efficient production by 0.4 GWh/a by 2030. (Kenkmann et al. 2011)

In the transport sector, one of the most important measures to reduce emissions is to promote cycling. Therefore it is recommended that investments in cycling infrastructure will be increased significantly and for instance connectivity with other forms of traffic will be improved and new parking spots for bicycles will be built. Public transport routes will be extended and departures will be quickened. Car sharing services will be promoted to reduce the total number of personal vehicles. (Kenkmann et al. 2011)

In the reference scenario of the climate protection strategy of Freiburg im Breisgau, the final energy consumption of the city would be decreased by 5% by 2020 and by 7% by 2030 compared to the level of 2005. Instead, in the scenario “Focus city” the final energy consumption is decreased by 14% by 2030. The biggest difference compared to the reference scenario is that a significant share of natural gas is replaced by biogas. Due to the growing amount of CHP production, total demand for fuels is higher than in the reference scenario. (Timpe et al. 2007)

The final energy demand of the city of Freiburg in Breisgau in 2010, 2020 and 2030 is calculated based on the target scenario (table 5.10). In the target scenario, demand for both heating oil and natural gas will be decreased by more than 500 GWh/a in 2010-2030. Also demand for electricity, district heating, petrol and diesel will be cut significantly by more than 200 GWh/a. Remarkable increases are expected in demand for ground heat, solar heating, biomass and renewable cooling. (Timpe et al. 2007)

Table 5.10. Energy demand by energy form in the target scenario in 2010, 2020 and 2030 (Timpe et al. 2007)

	Demand for various types of energy				
Energy form	**2010 (GWh/a)**	**2020 (GWh/a)**	**2030 (GWh/a)**	**Change 2010-2020 (%)**	**Change 2020-2030 (%)**
Biomass	101	129	135	28	5
Coal	34	11	4	-68	-64
Diesel	631	689	428	9	-38
District heating	1053	854	788	-19	-8
Electricity	1159	1008	866	-13	-14
Ground heat	49	114	132	133	16
Heating oil	634	262	83	-59	-68
Hydrogen/Fuel cells	0	3	9	N/A	200
Liquid gas	4	8	14	100	75
Natural gas	1001	841	454	-16	-46
Petrol	458	271	184	-41	-32
Renewable cooling	3	19	46	533	142
Solar heating	63	131	141	108	8

Energy saving potentials are defined separately for different consumer sectors (figure 5.4). In the target scenario, it is assumed that energy consumption for space heating of dwellings will be reduced by 70 % compared to the level of 2010 by 2050. The energy savings are planned to occur via reconstruction. Also the saving potential of domestic water heating is significant, almost 40%. On the contrary, savings of less than 1% are expected in electricity consumption of households. Sector small industries, trade and services is very diverse in the sense of energy demand. The energy saving potential for the sector is estimated to be 55 % by 2050 compared to 2010. The energy consumption of industry sector in Freiburg im Breisgau is to a great extend defined by one single company. Energy savings in industry sector can be reached by improving the processes. Despite the expected growth of the industry sector, final energy consumption of the sector could be reduced by more than 30 % by 2050. (Timpe et al. 2007)

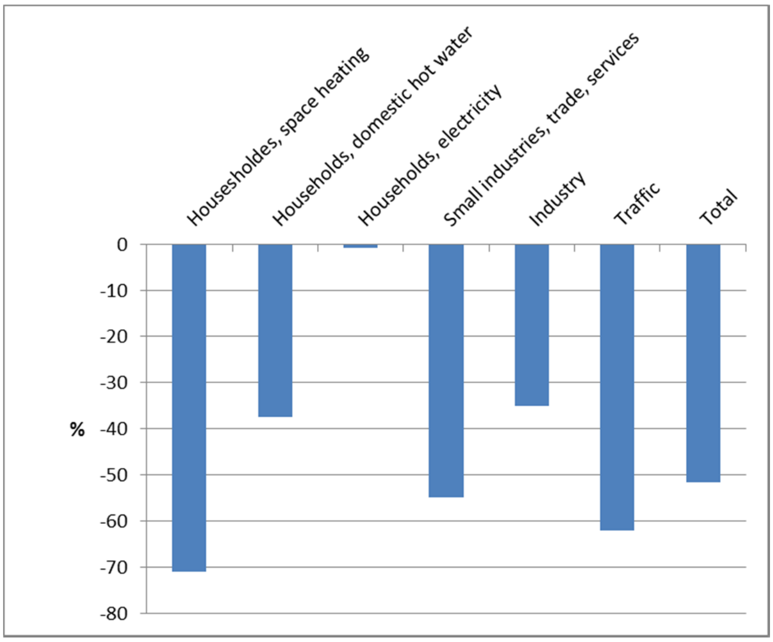

Figure 5.4. *Sectoral final energy saving potential compared to 2010 by 2050 (Timpe et al. 2007)*

5.2.8 The energy strategies of Hamburg

The city of Hamburg has established several documents that define the guidelines for the development of the city's energy sector. The most comprehensive valid document is the climate protection plan called "Masterplan Klimaschutz" from 2013.

In the climate protection plan, a vision for 2050 is presented, where CO_2 emissions would be reduced by 80%. In addition, subtargets for 2020 are described as well as concrete measures. Planned and implemented actions include agreements of co-operation with energy companies Vattenfall and E.On, construction and repowering of wind power plants and construction of 180 additional CHP plants. (Bürgerschaft der Freien und Hansestadt Hamburg 2013)

The agreement of co-operation between the city of Hamburg and Vattenfall AG contains measures for heat supply, modernization of the power grid and improvement of energy efficiency. In the heating sector, the goal is to achieve an ecological, economical heating system with good security of supply. The CHP plant Wedel could be replaced by a so called innovation power plant that consists of a combined gas and steam power plant and a heat storage. The heat storage would contribute to construction of more renewable energy units. Industrial waste heat and bioenergy could be utilized to a greater extent for heating networks. A new natural gas boiler is planned to be installed for peak and reserve power. (Freie und Hansestadt Hamburg, Vattenfall Europe Ag 2011)

The power grid of the city will be developed into a smart grid in order to improve flexibility and security of supply and to support the change towards usage of more renewable energy sources. Conventional electricity meters of the biggest electricity consumers will be replaced by smart meters. (Freie und Hansestadt Hamburg, Vattenfall Europe Ag 2011)

Another document with targets for the development of energy infrastructure is the agreement of co-operation between the city of Hamburg and E.On Hanse Ag. According to the agreement, district heating will be developed further by extending the district heating network and by adding new connections along the existing network. By 2025, the amount of households connected to the heating network should be increased by 20 % to 74 000. E.On Hanse Group plans to construct approximately 180 CHP plants with electrical capacity of 5 kW – 2 MW in the city region. The total electric capacity of CHP production should be increased by 8 MW to 17 MW by 2021. (Freie und Hansestadt Hamburg, E.On Ag 2011)

The heating network is planned to be opened for business partners for storage of energy from renewable sources. The partners will be able to supply heat to the grid, use it as a storage and also utilize when demanded. E.On Hanse group will contribute to the increasing utilization of industrial waste heat by providing information for construction of the systems. (Freie und Hansestadt Hamburg, E.On Ag 2011)

The contracting parties agree on support for development of a power to gas energy storage. Also new heat storages will be constructed so that by 2025 the storage capacity will be doubled. E.On Hanse Group is participating in a Callux field test of fuel cell heating devices. 100 devices have been installed in Hamburg and in the surrounding state Schleswig-Holstein. Also other devices such as a gas absorption heat pump are being tested. (Freie und Hansestadt Hamburg & E.On Ag 2011)

The Environmental program for a period from 2012 to 2015 by the city of Hamburg contains climate protection targets and plans for construction of renewable energy production capacity and energy storages. CO_2 reduction targets are -40% by 2020 and -90% by 2050 compared to 1990. High targets are set especially for housing sector, since heating and hot water supply are aimed to be carbon-free by 2050. The focus is on lowering energy demand of houses but also CHP production and heating methods based on renewable energy sources are promoted through a funding program. By 2025, the district heating network is planned to cover 520 000 residences. Various concepts for heating solutions of city blocks will be developed. Energy production targets include also doubling the wind power capacity to 100 MW and introduction of energy storages. A new Energy company, Hamburg Energie, owned by the city was established to support the development of renewable energy production capacity. Also co-operation with other Northern states is planned to be increased especially to promote wind energy production. To get a sufficient decision power over energy issues, the city of Hamburg purchased a 25.1% ownership of the district heating, natural gas and power-distribution networks (City of Hamburg 2012)

The Federal Ministry of Transport, Building and Urban Environment has selected Hamburg as one of the eight model regions for operation of electrical vehicles. Hamburg received 12.5 million euros of funding for establishing charging infrastructure. In 2012, there were in total 200 charging positions in public streets and in the sites of the companies that are participating in the Hamburg Electric Vehicle Program. The charging points deliver only power from renewable energy sources. (City of Hamburg 2012)

Energy consumption of buildings is stated to be one of the most crucial factors for achievement of energy targets. Energetic modernization of buildings is planned to be implemented by introduction of new standards that contribute to improved insulation and efficient heating systems. Target is to have nearly all buildings of the city renovated until 2050. Municipal buildings should serve as examples of high energy standards. All public buildings should be low-energy-houses at the latest in 2019, but Hamburg aims for reaching the target even earlier. (Bürgerschaft der freien und Hansestadt Hamburg 2013)

Energy demand of transport sector is planned to reduced be decreasing the need for traffic and by promotion of environmental-friendly means of traffic. Infrastructure for public transportation will be improved and bicycle and pedestrian traffic supported. (Bürgerschaft der freien und Hansestadt Hamburg 2013)

5.2.9 The energy strategies of Munich

In the part "Climate change and protection" of the Guideline Ecology, a target is set for the electricity sector to have 100 % of electricity produced from renewable energy sources by 2025. By 2020, 20% of total energy consumption of the city should be renewable energy. Energy demand will be reduced and energy efficiency improved in energy production for example by increasing CHP production. By improved energy efficiency and energy saving measures import of non-renewable fuels will be diminished. Dependence on imported energy will be diminished by improved energy efficiency, implementation of new renewable energy production units and diversification of procurement channels. (Landeshauptstadt München 2011) In the climate protection concept of Munich and five nearby municipalities, it is estimated that the share of renewable energy production could be 33% in heating sector, 63% in electricity sector and 7 % in fuels in 2030 (Karg et al. 2013).

Munich is clearly the biggest city in the Bavaria thus the Energy concept of Bavaria is also analyzed. In the whole federal state of Bavaria, hydro power production is planned to be increased from 12 500 GWh/a to 14 500 GWh/a. The increase will occur both by modernization and equipment of existing plants and construction of new plants. Wind power production is targeted to be 17000 GWh in 2021, whereas the current annual production is 600 GWh/a. Approximately 1000-1500 new plants need to be constructed before 2021. Geothermal energy is aimed to account for 1% of the total energy consumption in 2021. (Bayerische Staatsregierung 2011)

At the end of 2009, the total installed capacity of photovoltaic panels in Bavaria was 3900 MW. By 2021, the capacity is aimed to be increased to 14 000 MW so that solar power would account for 16 % of the final energy consumption of the region. In 2013, there were 500 000 solar collectors and 80 000 heat pumps in Bavarian buildings. The amounts are expected to be doubled annually in the upcoming years. In 2021, the share of energy production by solar collectors and heat pumps is targeted to be 4% of the total energy consumption, whereas the share was 0.5% in 2013. (Bayerische Staatsregierung 2011)

Bioenergy is already the most important renewable energy form in Bavaria accounting for 7% of the total final energy consumption and 6% of the total electricity consumption. In 2021, primary bioenergy production is aimed to be 50 000 GWh which would account for 9% of total final energy consumption and 10% of electricity consumption. Potential biofuels include biomass, biowaste, wood fuels and straw. More efficient conversion processes are being developed, e.g. gasification of biomass. (Bayerische Staatsregierung 2011)

The energy concept contains also plans for additional balancing power, energy storages and energy efficiency. Balancing power is planned to be mostly pumping-stations and gas turbine power plants, also biogas plants. Centralized CHP production as well as mini and micro CHP plants will be promoted to make energy production more efficient. Heat-power-cool plants will be developed to make CHP production economical also in warm periods. The energy efficiency and energy saving measures are planned to contribute to maintaining the electricity consumption at the current 23 600 GWh/a despite further electrification of the society. Energy consumption in buildings is aimed to be reduced by 20% until 2021. (Bayerische Staatsregierung 2011)

Stadtwerke München is the local energy company owned by the city of Munich. In 2008, the company launched a renewable energies expansion campaign that aims for increasing renewable energy production to approximately 7.5 TWh, an amount equivalent to the energy consumption of the city of Munich. Stadtwerke München has budgeted 9 billion euros for the construction of new renewable energy facilities. The key technologies of the campaign are hydropower, solar energy, bioenergy and wind energy. (Stadtwerke München 2013)

In the transport sector, the target for 2030 is to reduce the total kilometers driven with private cars by 5% compared to 2010, to replace 5% of private car kilometers with bicycle and pedestrian traffic and 10 % with public transportation. About 10% of private car kilometers should be driven with electrical vehicles that utilize renewable energy and 3% biogas vehicles. Railway traffic should be solely powered by renewable energy and buses should use solely biogas. (Karg et al. 2013)

In the part "Climate protection and climate change" in the "Guideline Ecology" for the city of Munich, a long-term target for becoming a 2000-watt society is announced. The concept means that the energy consumption per capita is limited to 2000 watts, but the concept is not accurately defined, hence it is not clear whether it means primary or final energy demand. For climate protection, maximum 500 watts will be produced by fossil fuels and the rest is supposed to be renewable energy sources. Reduction on energy consumption and improvement of energy efficiency are promoted in all sectors, especially in buildings and transport. (Landeshauptstadt München 2011)

Energy consumption of buildings accounts for 50% of the total CO_2 emissions of Munich and therefore the sector is crucial for reaching the energy saving targets. Modernization of the current building stock is stated to be the most efficient method to decrease energy consumption of the building sector. (Landeshauptstadt München 2011)

Targets for the building sector include further reductions on energy consumption of municipal buildings and support for energy consumption reduction in private sector through assistance and consultation. Investment conditions for climate friendly construction will be improved through new rental and support legislation and the city will confirm its role as a role model for energy efficient construction. (Landeshauptstadt München 2011)

Energy consumption is also aimed to be reduced through climate-friendly land use planning and transport. Promoted transport methods are public transport, pedestrian and bicycle traffic. Traffic amounts are also targeted to be reduced. (Landeshauptstadt München 2011)

The energy saving potentials of different forms of energy in 2010-2030 are estimated in the climate protection concept (table 5.11). The saving potential of electricity and heat is almost similar, whereas the saving potential of fuels is clearly lower. (Karg et al. 2013)

Table 5.11. *Energy saving potentials in Munich and municipalities of Baierbrunn. Gräfelfing, Kirchheim bei München, Schäftlarn and Unterföhring in 2010-2030 (Karg et al. 2013)*

Energy form	Reduction potential (%)
Electricity	18
Heat	19
Fuels	10

In the energy concept of the whole federal state of Bavaria, a target for total electricity consumption of the state is defined. According to the concept, the total consumption should stay at the current level during the next ten year despite the fact that usage of electricity consuming devices and actions will increase. (Bayerische Staatsregierung 2011)

5.2.10 The energy strategies of Wuppertal

The climate plan of Wuppertal lays out that the district heating network will be further extended and renewable energy forms that compete with existing district heating facilities will not be supported. The local energy company “Wuppertaler Stadtwerke” will promote the following actions: solar energy, wood pellet and wood chip boilers, heat pumps, natural gas vehicles, energy saving devices for households, small-scale CHP boilers, district heating and conversion of oil boilers to combust natural gas. (Brendel et al. 2009)

Companies are advised to utilize more waste heat. Also in energy production, a bigger share of the formed waste heat could be used. In 2007, the share of electricity from CHP plants was 17 %, but in the climate strategy increasing the share is set as a target. (Brendel et al. 2009)

In the final report of the document “Low Carbon City Wuppertal 2050”, distribution of energy sources in the final energy consumption for space heating in 2010 and in 2020 in different scenarios is presented (table 5.12). Scenarios are drawn up based on a target of reducing the CO_2 emissions in space heating of residential buildings by 80-95% until 2050, which is the official target of the federal government. (Reutter et al. 2012)

Table 5.12. *Distribution of energy sources in final energy consumption in space heating in 2010 and in 2020 according to three different scenarios (Reutter et al. 2012)*

	2010	2020		
	(%)	Reference scenario (%)	Scenario 80 % (%)	Scenario 95% (%)
District heating	9.8	10.3	10.6	10.9
Heating oil	32.1	29	26.5	23.9
Gas	48.4	49.7	46.4	43
Coal	1.6	1	1	1
Wood	1.6	2.1	3.4	4.6
Electricity	5.0	4.2	4	3.8
Heat pumps	1.4	3.3	3.7	4.1
Solar	0.2	0.4	4.5	8.6
Final energy consumption per person in buildings (MWh/a/cap)	7.2	7.01	6.85	6.09

The additional growth in utilization of renewable energy in space heating is planned to be implemented mainly by increasing solar energy production (table 5.12). Also the shares of wood and heat pumps are increasing rather significantly in the target scenarios. The growth of district heating is moderately positive in all scenarios. (Reutter et al. 2012)

In Wuppertal's climate strategy, promotion of bicycle traffic is planned to be carried out by improving the infrastructure, especially by developing and extending the bicycle road network and by increasing the number of parking spots for bicycles. The ecological and economical balances of alternative fuels natural gas, recycling biodiesel, and electric vehicles will be investigated when deciding measures for energy efficiency improvements. To develop the transport system in a sustainable way three goals are in a central role: the need for traffic should be reduced, technologies improved towards better energy efficiency and motorized private transport replaced by pedestrian and bicycle traffic. (Brendel et al. 2009)

The region Mettmann and the cities Remscheid, Solingen and Wuppertal carried out a pilot project "Regional Bioenergymanagement" in 2010-2011. In the report of the project, potential for bioenergy in the region is analyzed. The amount of total final energy potential of wooden biomass in the region is approximately 261 GWh. 36% of the potential is forest wood, 28% is old wood, 22% sawing waste and 14% from landscape conservation. (Valentin 2011)

Suggestions for further measures for promoting the utilization of bioenergy include waste heat recovery in existing biogas plants, wood pellet filling station, decentralized collection station for landscape conservation wood, projects for new short transition plantations and construction of new biogas plants. (Valentin 2011)

In the document "Energieeffizienz un Klimaschutz in Wuppertal – Bericht und Handlungsprogramm 2009-2020", the planned actions for improving energy efficiency are based on the six areas defined in the European Energy Award. The six action areas are:

Development planning and regional planning, municipal buildings and plants, procurement and waste management, transportation, organization and communication and co-operation. Most of the energy efficiency measures are related to energy consumption of municipal buildings. Municipal buildings are planned to be energetic reconstructed in parallel with the normal reconstruction rate. Control of energy and water usage in municipal buildings will be improved through computer aided facility management. All municipal buildings that are technically possible to be connected to district heating network will be connected. (Brendel et al. 2009)

It is stated in the study "Low-carbon city Wuppertal 2050" that the characteristics of a shrinking city can contribute to energy saving. Shrinking population enables reorganization of land-use and reduction of traffic amounts. It is also suggested that Wuppertal could act as a model for other shrinking cities in Germany by implementing innovative concepts in general and especially in projects that contribute to reduction of GHG emissions. (Reutter et al. 2012)

5.3 The role of bioenergy in the case cities

Chapters 5.1 and 5.2 gave an overview of targeted development of energy production mixes and energy consumption in the case cities, but a more detailed analysis on bioenergy–related plans is still needed. It was noticed that he case cities have drawn up and published a broad variety of documents and also energy companies and other local actors have their own strategies. The number and scope of documents is so great that a detailed and valid analysis is rather difficult to make. Therefore, the most relevant document from each city was selected for further analysis. The relevance of the documents was justified by their validity, the responsible bodies involved and by the subject of the document (table 5.13).

Table 5.13. *Analyzed climate and energy strategy documents (freely translated into English)*

City	Strategy document
Espoo	Climate Strategy for the Helsinki Metropolitan Area to 2030
Joensuu	Climate Programme of Joensuu 2013
Tampere	Climate and Energy Strategy of Pirkanmaa
Turku	Energy Strategy of Southwest Finland 2020
Vaasa	Energy Strategy and Action Plan of Ostrobothnia 2010-2020
Berlin	Energy Concept 2020
Hamburg	Masterplan Climate Protection
Freiburg im Breisgau	Climate Protection Strategy of the City of Freiburg
Munich	The Integrated Climate Protection Concept of Munich and five participating communities Baierbrunn, Gräfelfing, Kirchheim bei München, Schäftlarn and Unterföhring
Wuppertal	Energy efficiency and Climate Protection in Wuppertal - Report and Action Plan 2009-2020

The analyzed documents include energy concepts, climate protection plans and action plans on climate, energy and energy efficiency that are drawn up by the city administration or mandated by the city.

Targets and plans related to bioenergy were collected in more detail from the analyzed documents. Four cities have announced numerical targets for increasing bioenergy production (table 5.14).

Table 5.14. *Numerical targets of the case cities related to bioenergy (Timpe at al. 2007; Suck et al. 2011; Karg et al. 2013; Pirkanmaan liitto 2014)*

	Current situation	Target	Change
Tampere	Produced bioenergy in Pirkanmaa in 2012: recycled fuels 0 GWh/a, wood and other biomass 3238 GWh/a	Produced bioenergy in Pirkanmaa in 2020: recycled fuels 800 GWh/a, wood and other biomass 4600 GWh/a	Percentual change between 2012 and 2020: 42% in wood and other biomass
Berlin	Production of bioenergy in Berlin in 2008: 268.5 GWh/a of electricity and 731.6 GWh/a of heat	Reference scenario in 2020: electricity from biomass 732 GWh/a or 1184 GWh/a, heat 1785 GWh/a or 3140 GWh/a. Decentralized energy production from biomass 340 GWh/and 201 GWh/a biomass-based zone heating networks. Target scenario for 2020: electricity from biomass 920 GWh/a or 1221 GWh/a, heat 2946 GWh/a or 3730 GWh/a. Decentralized energy production from biomass 715 GWh/a and 236 biomass-based zone heating networks	Percentual change between 2008-2020 in electricity 173-355% and in heat 144-410 %
Freiburg im Breisgau	Bioenergy production in electricity sector in 2005 6,4 GWh/a	Reference scenario for 2020: bioenergy production in electricity sector 7,8 GWh/a. Scenario "Focus city" for 2020: bioenergy production in electricity sector 103 GWh/a	Percentual change between 2005 and 2020 in bioenergy -based electricity production 22-1509 %
Munich	Current electricity production: 9 GWh/a from waste, 8.5 GWh/a from biogas, 37.5 GWh/a from woodchips. Current heat production: 60 GWh/a from waste, 140 GWh/a from wood, 12.5 GWh/a from biogas	Electricity production in 2030, scenario 1: 9 GWh/a from waste, 22 GWh/a from biogas, 37.5 GWh/a from wood chips, scenario 2: 9 GWh/a from waste, 63 GWh/a from biogas and 37.5 GWh/a from wood chips. Heat production in 2030, scenario 1: 60 GWh/a from waste, 230 GWh/a from wood and 30 GWh/a from biogas, scenario 2: 60 GWh/a from waste, 320 GWh/a from wood and 93 GWh/a from biogas.	Percentual change until 2030 in electricity production: waste 0%, biogas 159-641%, wood chips 0% and in heat production: waste 0%, wood 64-129%, biogas 140-644%

Table 5.14 reveals that the increase in bioenergy production in the case cities is planned to be significant as all announced percentages are above 22%. However, most of the cities have various scenarios with clearly different bioenergy production amounts, and hence the level of actual increase is difficult to assess.

Since only few cities announce numerical targets for bioenergy production, national targets for energy production from biomass, biogas and bio liquids are collected from the NREAPs. To get an impression of the scope of the national bioenergy targets on city level, targets are allocated to the case cities in relation to the population numbers (tables 5.15 and 5.16.)

Table 5.15. *Estimated final consumption of solid biomass, biogas and bio liquids for energy production in Finland in 2010-2020 and allocation of targets to the case cities (Ministry of Employment and the Economy 2010)*

	Finland			
	Total (GWh)	**Biomass (GWh)**	**Biogas (GWh)**	**Bio liquids (GWh)**
2010	68 566	35 447	389	32 730
2020	96 297	53 682	968	41 647
Change in 2010-2020	27 731	18 235	579	8 917
Change per capita	5.11E-3	3.36E-3	0.11E-3	1.64E-3
Targets allocated to cities (change 2010-2020 in GWh)				
Espoo	1 290	848	27	415
Joensuu	377	248	8	121
Tampere	1 100	723	23	354
Turku	913	600	19	294
Vaasa	309	203	6	99

Table 5.16. *Estimated final consumption of solid biomass, biogas and bio liquids for energy production in Germany in 2010-2020 and allocation of targets to the case cities (Federal Republic of Germany 2010)*

	Germany			
	Total (GWh)	**Biomass (GWh)**	**Biogas (GWh)**	**Bio liquids (GWh)**
2010	179 582	104 909	25 622	49 051
2020	245 167	128 681	45 128	71 358
Change	65 585	23 772	19 506	22 307
Change per capita	0.81E-3	0.30E-3	0.24E-3	0.28E-3
Targets allocated to cities (change 2010-2020 in GWh)				
Berlin	2 852	1 034	848	970
Freiburg	187	68	56	63
Hamburg	1 465	531	436	498
Munich	1 122	407	334	382
Wuppertal	285	103	85	97

Targeted increase per capita in bioenergy production is clearly bigger in Finland than in Germany (tables 5.15 and 5.16). However, Germany has greater plans for increasing biogas and bio liquid usage. When comparing the targets on city scale and electricity consumption in the cities, the targeted increases are approximately in the scale of 30-60% of electricity consumption in the Finnish cities and 10-20% in the German case cities.

The specificity of bioenergy targets in the cities' strategies varies among the case cities. Some cities itemize the potential of various technologies in electricity, heat and transport fuel productions, whereas others only mention bioenergy production as one of the possible climate-friendly energy production methods. Bioenergy-related measures and technologies found in the case cities' strategies are listed in figure 5.5 (note: it is illustrated in how many strategies each technology is presented). Waste-to-energy technologies are also included in the figure even though only one fraction of waste is biodegradable and thus not all waste-to-energy production is related to bioenergy. CHP production in considered in cases where it is mentioned to be based on renewable energy production.

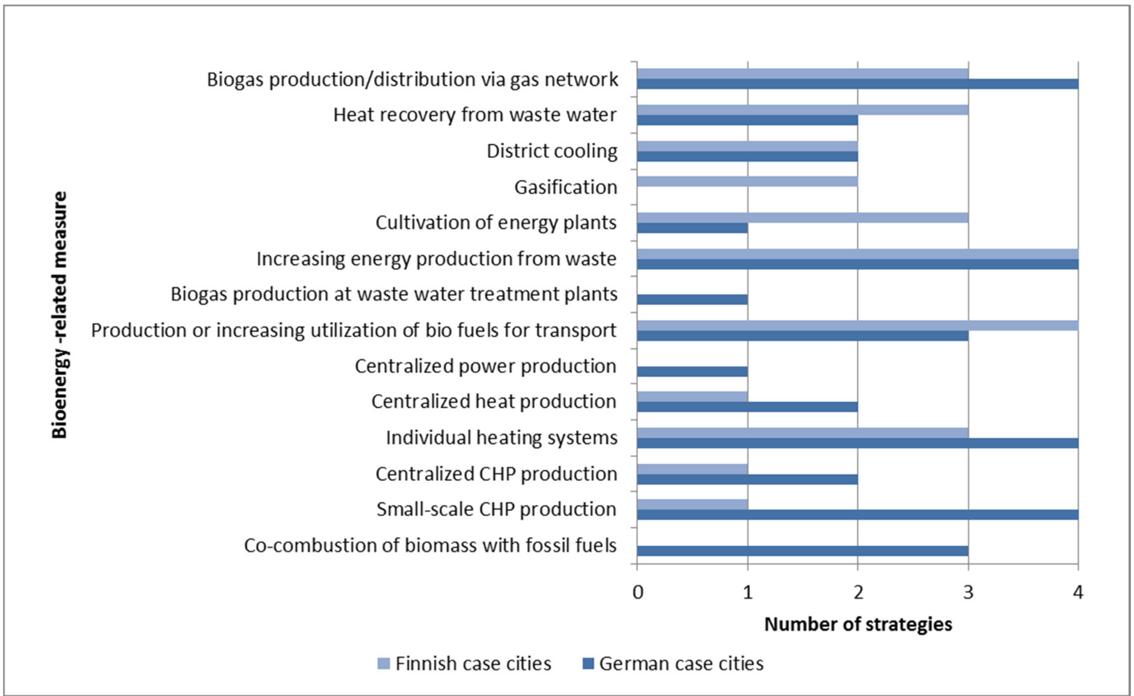

Figure 5.5. *Bioenergy-related measures reported in the analyzed strategies of the case cities (Anderson et al. 2007; Timpe at al. 2007; Brendel 2009; Suck et al. 2011; Uitamo 2011; Wasberg et al. 2012; Bürgerschaft der freien und Hansestadt Hamburg 2013; City of Joensuu 2013; Karg et al. 2013; Pirkanmaan liitto 2014)*

The most common bioenergy-related technologies in the Finnish case cities' strategies are energy production from waste and biofuels for transportation, that are both mentioned in four strategies (figure 5.5). Biogas production, heat recovery from waste water, cultivation of energy plants and individual heating systems are included in three strategies. In the German cities' strategies, the most often mentioned measures are related to biogas production, energy production from waste, individual heating systems and small-scale CHP production with biomass, that are found in four of the analyzed strategies (figure 5.5). Common actions include also biofuels for transport and co-combustion of biomass with fossil fuels, that are mentioned in three strategies. The biggest differences between the Finnish and the German case cities lie in cultivation of energy plants, small-scale CHP production and co-combustion of biomass with fossil fuels.

It can be concluded from the strategies that the case cities have planned to utilize bioenergy mainly for transport fuels and for heat or CHP production. On the other hand, many of the strategies were rather general, hence the planned role of bioenergy in the city’s future energy mix was not clearly explained. In addition, the scope of the energy strategies varies, and additional bioenergy-related plans may be found also in other strategy documents of the municipalities. For example, transportation-related targets may be listed in a separate transportation strategy instead of energy strategy.

6 REVIEW OF POTENTIAL BIOENERGY TECHNOLOGIES

The conclusion of the analysis of the case cities' strategies revealed that although the cities aim at significant increases in bioenergy production amounts, concrete plans and utilized technologies are still undecided or at least not announced in the published scenarios. Therefore, various technologies for bioenergy production are presented in this chapter. The focus is on modern technologies that can be assumed to become important parts of urban energy systems judged by the review of strategies and typical characteristics of cities.

6.1 Bioenergy production

Typical features of biomass-based fuels for energy production are high volatile and initial moisture content and low sulphur and heavy metal content. Otherwise properties are varied depending on for instance species and site of the raw material (Helynen et al. 2009).

In addition to biomass, waste is also in the focus of this study. Various waste flows are formed in cities: households, industry as well as services all produce waste. The type of industrial waste is city-specific, since the industrial structure and industrial processes involved vary between the cities. In many cases, industrial waste is caused by private companies who can also treat the waste by themselves. Therefore, the focus of this paper is on household waste and in this chapter especially on municipal solid waste (MSW).

The most common biomass conversion technologies for production of electricity and heat can be categorized into thermochemical and biochemical conversion routes. Thermochemical conversion routes include combustion, co-combustion and gasification, whereas anaerobic digestion and fermentation are the most important biochemical conversion technologies for energy production. Conversion processes can also include biomass upgrading, e.g. pyrolysis, torrefaction or pelletisation. In addition to heat and power production, bioenergy is also utilized as transport fuel in the form of e.g. biodiesel or bioethanol. There are several alternative bioenergy production paths depending e.g. on the feedstock and desired products (figure 6.1).

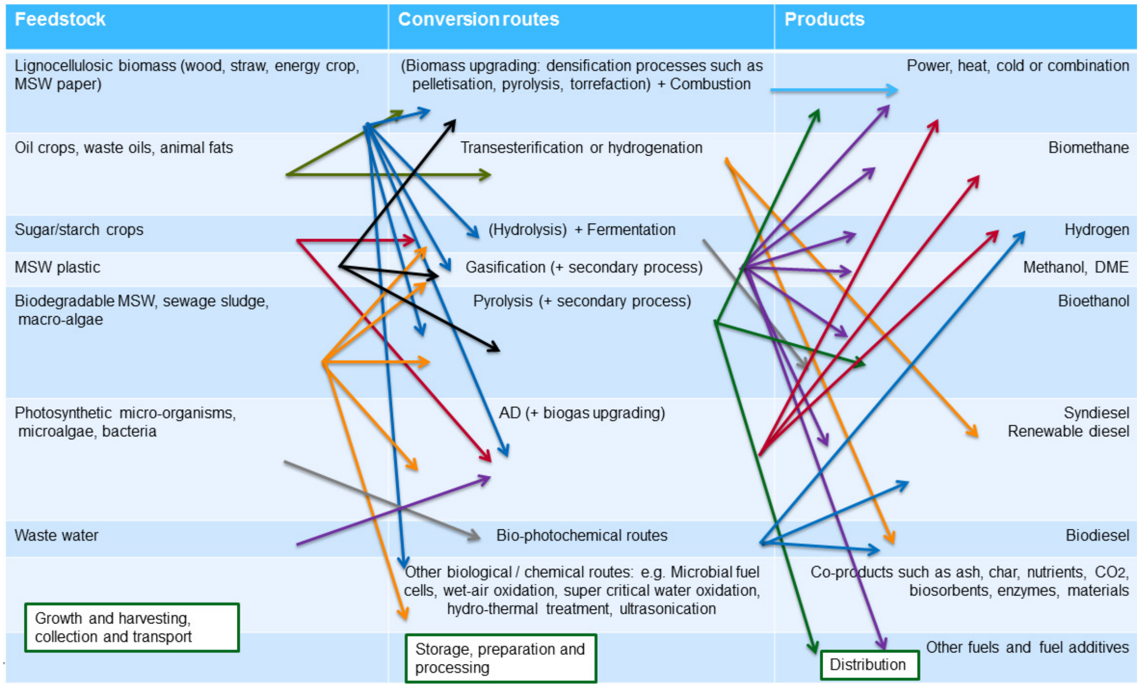

Figure 6.1*. Alternative feedstock, conversion routes and products of bioenergy production (adapted from IEA Bioenergy 2009)*

6.2 Combustion

Solid biomass can be classified into three groups: forestry, agricultural and waste-based feedstocks. Especially higher oxygen and lower carbon and sulfur contents set biomass apart from coal. Also high volatile content and quality variations are among the distinguishing characteristics of biomass. Woody biomass is typically more suitable for thermal combustion than agricultural crops, since wood-based biomass contains less chlorine. (Lu et al. 2011) Wood does not corrode furnace in low-efficiency CHP plants, but higher efficiencies require steam temperatures of at least 500°C and as a result, corrosive compounds are present in the superheaters. Technologies are under development to minimize the disadvantages of biomass combustion, but also co-combustion of biomass with fossil fuels prevent corrosion, since for instance peat and coal contain alkali-capturing compounds. (Helynen et al. 2009)

Fluidized-bed boilers are among the most potential technologies for combustion of biomass, since they are suitable for lower-quality fuels and fast quality variations (Hyppänen et al. 2002; Khan et al. 2011). In addition, fluidized-bed technology has low No_x and incombustible material emissions, inexpensive desulphurization (Hyppänen et al. 2002), uniform temperature distribution, efficient heat transfer between the bed and heat exchange surfaces, large solid–gas exchange area and stable combustion at low temperatures. The main disadvantages related to fluidized-bed combustion of biomass include high dust content in flue gas, need for efficient system for separation of gases and solids, erosion of boiler due to high velocities of solid particles and defluidization as a consequence of bed material agglomeration. (Khan et al. 2011)

There are two types of fluidized-bed boilers: bubbling (BFB) and circulating fluidized-bed boilers (CFB). In BFB boilers, fluidization medium remains in the bed, and because of the simple structure, the technology is rather cheap. Another advantage of BFB boilers is suitability to wet fuels. In CFB boilers, particles in fluidization medium are able to escape from the bed along with gases and must be returned back, and hence a circulation movement of particles is formed. Particle size in CFB boilers is smaller than in BFB boilers and gas velocities are bigger. CFB boilers are better suitable for coal combustion, since they have lower No_x and SO_x emission and higher burning efficiency. (Hyppänen et al. 2002)

MSW is a heterogeneous fuel whose main components are carbon, oxygen, hydrogen nitrogen, sulfur, moisture and ashes. Typical heating value of MSW is in the range of 8-12MJ/kg. Heterogeneity and varying moisture content as well as feedstock composition of MSW makes combustion more complex than that of e.g. coal. MSW is formed at a relatively constant rate throughout the year and the production amount can be estimated based on number of population and a residue factor that is around 400 kg per person per year in industrialized countries. Based on a life-cycle assessment, typically 67% of municipal solid waste can be considered as carbon-neutral and 33% of fossil origin. (Qiu et al. 2009)

Waste incineration has served traditionally as base load provider in power and district heating grids. Waste energy could also be used as balancing power if certain waste fractions or waste derived fuels are stored and utilized in case of shortage of other energy sources. In many cities, both energy and waste sector are managed by municipal actors and therefore joint planning is relatively easy to be put into practice. (Münster et al. 2013)

One of the obstacles for wider construction of waste incineration plants has been public opinion, since before the modern emission regulations and cleaning technologies, waste incineration plants caused serious environmental problems. The residues from waste incineration contain both hazardous materials and valuable resources such as various metals. Out flows of waste incinerators include bottom ash and air pollution control residues. (Brunner et al. 2009)

Especially fluidized-bed incinerators have attracted attention in the previous years, but also more conventional grate-type incinerators are still popular. The main advantage of grate-type boilers is the fact that no pretreatment processes for MSW are needed before incineration. Also a combination of both technologies, a so called grate-CFB, has been developed for gaining the advantages of both technologies. (Zhang et al. 2010)

Usually many harmful compounds are formed in the flue gases in combustion of waste materials. Typical emission are e.g. gaseous SO_2 and No_x, dioxins, organic compounds, metals and small particles. In order to operate waste-to-energy plants in an environmental-friendly way, emissions must be managed. Optimal design of cleaning devices depends on the waste type and combustion technology used. (Lind et al. 2007)

Combustion is typically combined with some other process in order to generate electricity. Alternative methods for production of electricity or heat include Rankine cycle, Organic Rankine Cycle (ORC) and Stirling Engines. (Nussbaumer 2003) Rankine cycles with water and steam are the most conventional processes used for electricity generation. When an organic fluid is used instead of water, the process is called ORC. ORCs can be used for heat recovery in relatively low temperatures, since the organic high molecular mass fluids are supposed to have lower boiling points than water. Similarly to other Rankine cycles, also in ORCs heat is converted into work e.g. through an expander and further into electricity in a generator. The main components of the cycle are an evaporator, an expander, a generator, a condenser, a reservoir and a pump. ORC is argued to be suitable especially for heat sources at temperatures lower than around 370°C and thus suitable for e.g. recovery of industrial waste heat. (Yu 2014)

6.3 Co-combustion

By co-combusting biomass in existing fossil fuel-fired power plants, GHG emission can be reduced with relatively low investment costs. In addition to the fact that biomass is considered as a carbon-neutral fuel (Agostini et al. 2013), biomass has a lower hydrogen/carbon ration than coal or oil, which denotes to smaller CO_2 emissions. Since also generation costs are considered low compared to other bioenergy production options, co-combustion is among the potential bioenergy technologies. Combustion is a mature technology, also for large-scale applications, co-combustion with coal or peat may have a positive effect on corrosion tendency and co-combustion can be utilized even when the available biomass feedstock is limited. Especially mixing solid biomass with coal has potential, since the number and scale of coal-fired plants is great, hence mainly a mixture of coal and biomass is analyzed in the chapter. (Basu 2013) Also, many waste-based fuels are suitable for co-combustion in existing fluidized-bed boilers. The better the quality of the waste is the higher efficiency rate and power-to-heat ratio can be reached. (Helynen et al. 2009)

Even though co-combustion of biomass with fossil fuels is a common technology for reduction of the GHG emissions in existing fossil fuel-fired plants, it involves also various challenges that are connected to different characteristics of biomass and fossil fuels. Co-combustion of biomass has been noticed to reduce thermal efficiency of fossil fuel-fired plants and the reduction is proportional to mass percentage of biomass in the fuel. The most crucial differences between solid biomass and coal include:

1. different grinding behavior due to the more fibrous and breakable structure of biomass particles
2. hydrophilicity of biomass and hydrophobicity of coal
3. heterogeneous and variable characteristics of biomass and homogenous and constant characteristics of coal
4. high H/C and O/C ratios in biomass and low in coal
5. and higher concentrations of compounds that cause corrosion, slagging and fouling in the ash in biomass. (Basu 2013)

Many of the obstacles related to co-combustion of biomass with fossil fuels can be avoided or diminished by torrefaction of biomass. Torrefaction changes the particle structure of biomass so that it becomes more similar to that of coal. After torrefaction, same grinders can be used for both coal and biomass without additional energy demand. Also the need for additional storages can be avoided by torrefaction, since torrefied biomass is hydrophobic and can be stored outdoors uncovered. Despite the varied quality of feedstock, torrefied fuel has a rather constant quality with less variation in heat content and combustion characteristics. (Basu 2013)

Co-combustion can be direct, indirect or parallel. In direct co-combustion, both coal and biomass are fed directly into the same boiler after common or separate preparation processes. Co-combustion is a relatively simple technology with low costs and hence it is the most common type of co-combustion processes. However, direct co-combustion is best suitable only for low biomass to coal ratios. When using torrefied fuel instead of raw biomass, biomass to coal ration can be increased and operational difficulties reduced. (Basu 2013)

In indirect co-combustion, solid biomass is first gasified and then the product gas is combusted in the same furnace with the fossil fuel. The main advantages of indirect co-combustion are that it is applicable to a wide range of fuels and that the alkali compounds from the biomass can be removed before combustion, which leads to less fouling and corrosion. (Basu 2013)

Parallel co-combustion involves combustion of biomass in a separate boiler and utilization of the produced steam in the steam process of the fossil fuel plant. Usage of a separate boiler increases reliability of the plant and helps to avoid most of the corrosion and fouling related to combustion of biomass. However, parallel co-combustion demands high capital investments compared to other types of co-combustion. (Basu 2013)

6.4 District cooling

Since the usage of space cooling is increasing, interest towards centralized cooling system has risen. In district cooling systems, cooling is produced in a centralized unit and distributed in the form of cold water or other media to customers via a similar pipeline network as in district heating. However, in district cooling networks, temperature difference between feed water and return water is smaller than in district heating networks, only about 10°C. Due to the lower temperature difference, dimensions of pipelines must be larger and hence costs are increased compared to district heating networks. If district cooling is utilized, individual cooling devices do not need to be maintained and operated and the absence of cooling devices also leaves space for other purposes in properties. (Söderman 2007)

Cooling can be produced by four alternative types of methods: absorption cooling equipment, compressor technology, heat pumps or by using free cooling by utilizing directly for example cold sea water (Finnish Energy Industries). The most related option to bioenergy is production of cooling by using the waste heat from biomass-fired CHP plants.

One potential option for production of cooling is to generate the cold combined with CHP production. CHP is a mature technology that is utilized in many energy production plants. CHP production has better efficiency than separate production of heat and power. The efficiency can be improved further if production of cooling is integrated to the process. Simultaneous production of heat, power and cool is called combined cooling, heating and power production (CCHP) or tri-generation. Fuel efficiency of CCHP systems is typically approximately 70-90%. (Wu et al. 2006)

The main components of CCHP plants are similar to those of a CHP plants: a prime mover, an electricity generator, a heat recovery system and control systems. In addition, thermally activated equipment is needed in CCHP plants for production of cooling. Cooling production technologies include e.g. absorption or adsorption chillers and desiccant dehumidifiers. Every cooling and dehumidification system has its own optimal working temperature, so the selection of cooling systems depends on the used prime mover and its temperature range. The most common prime movers are steam turbines and other popular prime movers include reciprocating internal combustion engines and combustion turbines, whereas micro-turbines, Stirling engines and fuel cells represent newer prime mover technologies. (Wu et al. 2006)

CCHP systems can be classified into four types based on the scale of production. Micro systems have capacities under 20 kW and are argued to have potential for commercial, institutional and residential utilization. The most potential prime movers for micro systems are expected to be reciprocating engines, fuel cells and Stirling engines. (Wu et al. 2006)

Capacities of small-scale systems are in the range of 20 kW - 1 MW. Small-scale CCHP systems are stated to be the most mature type of CCHP production. Small-scale CCHP systems are suitable e.g. for small industry, hospitals and retail stores. The most common prime mover for small-scale applications is reciprocating internal engine, but also micro turbines have great potential. (Wu et al. 2006)

Medium systems are in the scale of 1-10 MW and typically found in industrial sites. Large-scale systems have capacities above 10 MW and are suitable for large industries or districts. Large-scale CCHP applications are still rather rare, although large-scale CHP production is a widely used technology. (Wu et al. 2006)

6.5 Biomass gasification

Gasification is thermochemical process for production of gaseous fuels from liquid or solid biomass. Gasification is rather similar to combustion, but unlike in combustion, chemical compounds do not get broken and release energy. Instead, chemical compounds are stored in the product gas with the energy bound to them. During gasification, the H/C ratio of biomass is increased. (Basu 2013)

Gasification process starts with warming of the particles to the drying temperature, where moisture content of biomass is lowered. Secondly, dried biomass is pyrolysed. During pyrolysis stage, solid biomass is converted into gaseous and tarry products by supplying heat. Volatile matter is pyrolysed and the remaining solid matter is called char. The actual gasification starts after pyrolysis. In gasification, reactive molecules in the gasification atmosphere diffuse into the fuel particles and react with the char. (Saastamoinen 2002) The most important reaction in the gasification step is the gasification of char formed in pyrolysis. Biomass char is clearly more porous and reactive than that of coal char, which results in different reaction behavior. In gasification, biomass char is reacted with gasification agents such as oxygen, steam and carbon dioxide producing gases with low molecular weight. (Basu 2013)

As gasification is characterized by high temperatures and conversion rates it is a suitable technology for energetic utilization of waste. The main advantages of gasification compared to incineration include lower operation temperature, lower dioxin, furan and NO_x emissions and in some cases better efficiency. In addition, the gasification products can be used in various applications for energy production or also other purposes such as chemical manufacturing. Low operating temperatures reduces the amount of volatilized heavy metals and alkalis. (Arena 2012)

Demand for energy-consuming pretreatment of flue gas decreases the total efficiency of waste gasification. As a consequence, incineration has in many cases better efficiency than gasification when also pretreatment processes are considered. (Arafat et al. 2013) It is stated that the main technical improvement needed for wider usage of waste gasification technology include cheaper and better gas cleaning systems, higher electricity conversion efficiency and better ability to meet desired specifications. Many different types of waste gasifiers are already commercially available. (Arena 2012)

Gasification processes can be classified into different types depending on five factors: pressurization, gasification rate, gasification medium, reactor type and gas cleaning method. The main types of gasification reactors are fluidized-bed reactor, fixed-bed reactor and entrained flow reactor. Especially fluidized-bed reactor is suitable for biomass gasification but there are also applications that utilize a fixed-bed reactor for gasification of biomass. Entrained flow reactors are used for biomass only when biomass is co-gasified with coal. Fluidized-bed reactors are typically pressurized, air is used as gasification medium is air and gas cleaning method is hot cleaning. One of the main challenges in biomass gasification is tar formation, but when using fluidized-bed reactors, tar formation is low. (Kurkela et al. 2002) Fluidized-bed reactors are typically used for plants of medium size with thermal input of approximately 1-100 MW, whereas fixed-bed reactors are best suitable for smaller and entrained flow reactors for greater thermal inputs (Basu 2013).

Gasification process can be combined with a boiler and steam cycle, a gas turbine or a fuel cell. Integrated gasification combined cycle (IGCC) plants consist of a gasification unit, product gas cleaning system and a gas turbine. IGCC technology is still in demonstration stage and most of the existing plants use coal as a fuel. The efficiency rate of power production in the existing demonstration plants is 45-56%, which is higher than in conventional condensing plants. Other advantages include low flue gas emissions and potential for efficient capture of CO_2 before combustion. The existing demonstration plants are large-scale coal condensing plants. In large-scale applications, oxygen production and wet gas cleaning technologies can still be economic. Instead, in medium and small-scale applications, usage of oxygen as gasification medium and utilization of wet gas cleaning would not be economically reasonable. Therefore, a process called simplified IGCC has been developed for medium-sized (30-150 MW_e) applications. Simplified IGCC process is based on gasification with air and it is suitable also for gasification of solid biomass especially in CHP production. The power-to-heat ratio of IGCC plants for district heating production is around 0.8-1.2 when wood fuels are used, which means that the ratio is almost two times as big as in conventional back-pressure steam power plants. Electrical efficiency of the process is around 40-45% and total efficiency 85-90%. It is estimated that only in Finland, the power production capacity could grow by 1000 MW if simplified IGCC processes were used to meet the current heat demand instead of other CHP production. (Kurkela et al. 2002)

In integrated gasification fuel cell cycle (IGFC) plants, the gasification products are used as a fuel for a fuel cell after a cleaning process where substances that can cause fouling are removed (Naraharisetti et al. 2014). The main components of fuel cells are two electrodes separated by ionic conductor called electrolyte. Electricity is generated in fuel cells directly from the chemical energy of the fuel and also heat can be recovered from the process. Fuel cell technology has low or zero emissions, its operation is flexible and it is capable for integration to other systems. Fuel cell types are classified by the electrolyte used. (Omosun et al. 2004) Especially solid oxide fuel cells (SOFCs) are argued to be suitable for integration with biomass gasification units (Omosun et al. 2004; Naraharisetti et al. 2014). The SOFC is one of the simplest fuel cell types, and it uses oxide ion-conducting ceramic as electrolyte. The SOFCs operate at high temperatures, around 850°C, because also gasification products have high temperatures and thus integrated processes with high efficiency rates can be achieved. (Naraharisetti et al. 2014) However, hot gas cleanup process is a more expensive and less mature technology than cold gas cleanup (Omosun et al. 2004).

6.6 Anaerobic digestion

Anaerobic digestion (AD) is biological process in the absence of oxygen for production of biogas and reduction of organic matter such as biowaste. Feedstock for AD is liquid waste such as wastewater, but the process is also suitable for the treatment of solid biomass such as MSW. (Mata-Alvarez 2003) The main components of produced biogas are methane (55-80%) and carbon dioxide (20-45%). There are several alternative types of anaerobic digesters and the optimal design depends e.g. on the substrate type, scale of the plant and operational parameters. (Nizami et al. 2013)

Potential development paths of AD include co-digestion of lignocellulosic substrates with other substrates, and controlling of AD process and methods for handling CO_2 during biogas upgrading process (Nizami et al. 2013). Drawbacks related to properties of a specific substrate can be avoided by co-digestion of two substrates. Such drawbacks include for example presence of potential inhibitors for methanogenic activity. Co-digestion can occur for example by sewage sludge and organic fraction of municipal solid waste. (Mata-Alvarez et al. 2013)

One of the main applications of AD for urban environments is production of biogas at wastewater treatment plants (WWTPs). There are several option for the treatment of biogas from WWTPs (table 6.1). (Venkatesh et al. 2013)

Table 6.1. *Advantages and disadvantages of alternative treatment methods for biogas from WWTPs (Venkatesh et al. 2013)*

Biogas treatment method	Advantages	Disadvantages
Release of biogas	No need for investments in energy-recovery infrastructure	Possibly harmful environmental effects, no energy revovery
Biogas flaring	Reduced environmental effects compared to release	Possibly harmful environmental effects that can be reduced by scrubbing and cleaning of the exhaust gas, no energy revovery
Heat utilization in plant	Reduced dependence on external heat sources	Investments in heat production equipment, operation and maintenance costs
Electricity generation at the WWTP	Reduced dependence on grid electricity	Investments in electricity generation equipment, operation and maintenance costs, environmental effects if the exhaust gas is not cleaned
CHP production at the WWTP	Better efficiency compared to electricity generation only and heat production only, reduced dependence on external energy	Investments in electricity generation and heat recovery equipment, operation and maintenance costs, environmental effects if the exhaust gas is not cleaned
Sale of heat	Sales revenue	Investments in heat production equipment and piping, heat losses during transmission, dependence on exernal heat is not reduced
Sale of electricity to grid	Sales revenue	Investments in electiricy generation equipment, dependence on exernal electricity is not reduced
Upgrading of biogas and conversion to transport fuel or distribution via gas grid	Sales revenue	Investments in upgrading setup, operation and maintenance costs
Piping of biogas without upgrading	Less sales revenue	Investments in piping

The most suitable treatment method for biogas from WWTPs should be chosen based on e.g. expected revenues for the sales of heat and fuels and the environmental benefits gained by replacing fossil fuels with biogas in energy production. Different treatment methods can be utilized also combined. (Venkatesh et al. 2013)

When biogas is upgraded into biomethane, the composition is similar to natural gas and hence biomethane can be used to replace natural gas in all applications, such as gas turbines and domestic heaters, and with no adjustment requirements. Injection of biomethane into existing natural gas networks is an alternative for storage and distribution of biomethane. Since biomethane can be used for the production of both heat and electricity and also as a transport fuel, biomethane has potential to contribute significantly to GHG emission reduction. (Urban 2013)

When implementing injection of biomethane into existing natural gas network, the investment needs mainly limit to grid connections. Upgrading facilities must be connected to the gas network via a feed-in station. The main components of a feed-in station are compressor, gas conditioning or gas mixing facility, connection pipeline and various metering and process control devices. (Urban 2013)

The main barrier for implementation of biomethane injection into natural gas network is argued to be its cost. Also controlling the gas network with increasing number of injection points and balancing supply and demand are considered as challenges. However, especially due to the fact that more fluctuating power production methods are expected to be installed, for example wind and solar power, there will be increasing demand for storable energy sources such as biomethane. (Urban 2013)

6.7 Pyrolysis

Pyrolysis is a thermochemical conversion process that is used for decomposition of biomass into bio oils or bio char. Biomass is heated to a so called pyrolysis temperature, typically 300-650°C, in the absence of oxygen and after a specified time in the temperature, condensable gases and solid char are formed. While condensing, the gases turn into bio oil, char and non-condensable gases. The produced bio-oil consists of complex hydrocarbons, oxygen and up to 20% water. Usually, the main product of the process is bio-oil, that has a lower heating value of 13–18 MJ/kg wet basis, but also non-condensable gases and solid char can be utilized. In summary, complex hydrocarbon molecules decompose into smaller and simpler molecules during pyrolysis. (Basu 2013)

Pyrolysis reactions can be divided into two basic types, fast and slow. In fast pyrolysis, the time used for heating the fuel to the pyrolysis temperature is shorter than the pyrolysis reaction time, whereas in slow pyrolysis the heating time is much longer than the reaction time. Slow pyrolysis is mainly used for char production and it is called either torrefaction or carbonization, depending on the temperature used. In contrast to slow pyrolysis, fast pyrolysis is used primarily for the production of bio-oil or gas. There are two main types of fast pyrolysis processes: flash and ultrarapid pyrolysis. The characteristics of flash pyrolysis are fast heating time and pyrolysis temperatures of 450-600°C. Ultrarapid pyrolysis involves highly fast heating time and pyrolysis temperatures of around 650°C for production of liquids and 1000°C for the production of gas. A special type of pyrolysis takes place in the presence of a medium, typically water or hydrogen. Usually the term pyrolysis is used only for the production of liquid yield although the general definition contains also other thermal decomposition processes torrefaction and carbonization. (Basu 2013)

By varying the operating parameters of the pyrolyser the share of the desired main product, which can be char, liquid or gas, can be increased. The main parameters are heating rate, final temperature and gas residence time (table 6.2). (Basu 2013)

Table 6.2. *Optimal operating parameters for pyrolysers depending on desired final product (Basu 2013)*

Desidered final product	Heating rate	Final temperature	Gas residence time
liquid	high	moderate (450-600°C)	short
char	slow	low	long
gas	moderate or slow	high (700-900°C)	long

In addition, the size of biomass particles affects the heating rate and therefore also the composition of the yield. Fine biomass particles produce more liquid yield, whereas larger particles sizes result in more char production. (Basu 2013)

6.8 Torrefaction

Similarly to pyrolysis, torrefaction is also a thermal decomposition process and as mentioned above, torrefaction is actually one type of pyrolysis processes. The principle difference compared to carbonization and pyrolysis is that by carbonization, fixed char content is aimed to be maximized and in pyrolysis, the main product is liquid, whereas in torrefaction, the energy content and mass yields should be maximized. In torrefaction, the carbon content of biomass increases while the oxygen and hydrogen contents decrease, which results in higher energy density. Torrefaction is mainly used for making the texture of biomass better suitable for pelletizing. Torrefaction process is rather similar to that of pyrolysis, but the heating rate must be slower to maximize the solid yield (table 6.2). Optimal temperature of the process is assumed to be 200-300°C. (Basu 2013)

Torrefaction reduces both the mass and density of biomass. In addition, the size of particles decreases, the variation of particle sizes reduces and the particle structure becomes more brittle and less fibrous. The changes in particle structure are favourable for grinding and pulverization, but on the other hand, storage of torrefied biomass contains a risk of fire and explosion. The moisture content of biomass decreases by about 90% during torrefaction process. Torrefied biomass is also almost hydrophobic and does not absorb moisture easily, which improves storability of torrefied biomass. (Basu 2013)

The main operations in a torrefaction plant are feedstock handling, preparation, drying, torrefying, and cooling. Torrefaction reactor is the most crucial part of the plant and reactors can be classified into five different types based on modes of heat transfer and solid contacting. The five main reactor types are: convective bed reactor, rotating drum reactor, fluidized-bed reactor, microwave reactor and hydrothermal reactor. (Basu 2013)

6.9 Pelletising

Pelletising process typically consists of drying, grinding, actual pelletising and cooling steps. Optimal characteristics of biomass feedstock are small particle size and moisture content below 10-15%. Some process types allow also higher moisture content. In pelletising, high pressure is used for pressuring biomass into cylindrical pieces with high energy density. The quality of the fuel produced is rather uniform and constant and the net caloric heating value is approximately 16-18 MJ/kg. The final heating value depends mainly on the moisture content, which is typically in the range of 5-10%. Typically, the thermal efficiency of pelletising process is assumed to be approximately 94% and net efficiency 87%. (Uslu et al. 2008)

Current research on pelletising technology aims at improving the quality of pellets and reducing the energy demand of the processes. A process called steam explosion,that is on demonstration stage, is argued to produce harder and denser pellets that are less sensitive to moisture and fines separation. Another process type has been developed for lower operation temperatures (55-60°C) and higher moisture contents of biomass (30-35%). Because of low temperature and minor need for drying, both energy consumption and investment costs are clearly smaller than in conventional pelletising processes. (Uslu et al. 2008)

6.10 Biofuel production

Liquid biofuels and biogas can contribute to diminishing the oil-dependence of the transport sector and to reduction of GHG emissions. Sustainability of biofuels is promoted in the EU by a sustainability criterion (Directive 2009/28/EC).

One of the focus areas in biofuel development is second-generation biofuels that are also known as advanced biofuels (Helynen et al. 2009). First generation biofuels are often produced from food crops, which causes sustainability issues if biofuel production competes with food production for the use of fertile land. Instead, feedstock for production of second generation biofuels is non-food biomass, and the production process is aimed to be more cost-efficient and contribute to greater CO_2 reductions than first-generation biofuels. However, improvements are still needed e.g. in conversion efficiency and investment costs before production of second-generation biofuels is fully competitive. (Fiorese et al. 2013)

6.10.1 Biodiesel

Biodiesel is a biodegradable fuel that can be used as a substitute for diesel. Biodiesel is a non-toxic, almost sulphurless and non-aromatic fuel, hence it can contribute to exhaust emission reductions. Usage of biodiesel reduces CO emissions by approximately 20%, HC emissions by 30%, particulate matter emissions by 40% and soot emissions by 50%. However, No_x emissions increase by 10-15%, but the increase can be neglected by injection timing. (Canacki et al. 2008)

The most common production route for biodiesel in transesterification from food-grade vegetable oils. In addition to transesterification, other alternative production methods include dilution, microemulsification and pyrolysis. Interest towards other potential feedstock, such as waste cooking oils, restaurant greases and animal fats, is increasing mainly due to the high price of food-grade vegetable oils. (Canacki et al. 2008)

The price of feedstock determines a great share of the cost of biodiesel, and to make biodiesel economically competitive to diesel, feedstock cost should be lowered. Therefore, as mentioned above, low-cost feedstock alternatives including e.g. waste cooking oils and animal fats are of interest in biodiesel production. However, low-cost feedstock typically contain free fatty acids (FFAs), and high concentrations of FFAs prevent the usage of alkaline catalyst, which is usually used transesterification. Instead, potential biodiesel production processes are for instance supercritical transesterification and acid-catalyzed transesterification. (Canacki et al. 2008)

6.10.2 Bioethanol

Bioethanol can be produced from sucrose containing, starchy or lignocellulosic feedstocks. Utilization of lignocellulosic biomass is considered as the feedstock with the greatest potential due to its availability and low cost, even though large-scale commercial production has not yet been introduced. The basic steps of bioethanol production are fermentation, distillation and dehydration (Cardona et al. 2007)

Since lignocellulosic biomass has a complex structure, pretreatment needs to be included in the conversion process. As a result, production costs of bioethanol from lignocellulosic biomass are higher than when e.g. sucrose or starchy feedstocks are used. However, agricultural by-products as well as industrial and municipal wastes are all suitable for ethanol production also in large-scale, and since their usage denotes low feedstock costs and improved energy recovery from waste, it is expected that lignocellulosic biomass will become the main feedstock for bioethanol production. (Cardona et al. 2007)

Bioethanol is typically mixed with gasoline if used as a transport fuel. If the share of bioethanol is not more than 10%, the fuel is suitable for normal gasoline cars. Flexible fuel vehicles can also use fuels with 85% of bioethanol. Biodiesel is a common term for fatty acid methyl and ethyl esters. A new process of hydrogenating oils and fats is one option for production of biodiesel. Synthetic biodiesels can also be used as such or mixed with gasoline. (Viinikainen et al. 2009)

7 POTENTIAL ANALYSIS OF BIOENERGY TECHNOLOGIES TO URBAN ENVIRONMENTS

Potential bioenergy-related technologies were described on a general level in chapter 6 and their suitability to city environments is analyzed in more detail in this chapter. Estimations on the maturity rate of the technologies are presented in order to find out the reliability and attractiveness of each technology. In addition, judging from the typical characteristics of cities identified in chapters 2 and 5, the advantages of the analyzed technologies especially to urban environments are evaluated.

7.1 Development status of bioenergy technologies

The maturity of technologies described in chapter 6 varies greatly. The timescale of scenarios for the development of urban energy affects the range of technologies that can be assumed to be available for commercial use. Most of the scenarios presented in this paper are for the years 2020-2030, which implies that technologies that are at a very early development stage will most likely not be reasonable and serious alternatives.

Therefore, estimations found in literature on the development status of selected bioenergy technologies are presented and compared. Basis of the analysis is on experts' opinions about the development statuses of the technologies (Fiorese et al. 2013, Fiorese et al. 2014) and on the technology review in the Annual report of IEA Bioenergy (2009). In addition, information from chapter 6 is used for evaluating the development statuses.

Bioenergy technologies are divided into four statuses: commercial, early commercial, demonstration and research and development (R&D) (figure7.1). Some of the technologies could not be unambiguously categorized under the four categories, for example some variations of AD are commercial and others early commercial, but in those cases different references were compared and the most suitable headline was selected.

Commercial	Early commercial	Demonstration	R&D
Combustion for heat production	Parallel co-combustion	Pyrolysis	IGFC
Combustion + steam cycle	Biogas injection into natural gas network	ORC	Torrefaction
CHP production	Gasification	Stirling engine	
Direct co-combustion	AD	Indirect co-combustion	
Steam turbine	Production of second-generation biofuels	IGCC	
Gas turbine	District cooling		
Waste incineration	CCHP		
Production of first-generation biofuels			
Pelletising			

Figure 7.1*. Development statuses of analyzed bioenergy technologies (Helynen et al. 2009; IEA Bioenergy 2009; Arena 2012; Consonni et al. 2012; Fiorese et al. 2013; Kohl et al. 2013; Fiorese et al. 2014)*

Previously analyzed technologies, especially torrefaction and IGFC seem to be at an early development stage (figure 7.1). Also rather similar types of technologies, pyrolysis and IGCC, are still relatively immature, and hence it is questionable if they will be fully commercialized until 2020. Most other technologies are considered as commercial or early commercial and hence they are potential options for cities.

Many of the case cities stated that they wanted to gain a reputation of being a forerunner in implementation of modern low-carbon energy technologies. Therefore, it is also possible that technologies that are on early development stages will be implemented in the case cities e.g. as demonstration plants.

7.2 Potential of bioenergy in urban environments

According to the national and municipal strategies analyzed in chapters 2 and 5, CHP production is among the favoured energy production methods. Although the feedstock or other characteristics of CHP plants is in most cases not described, renewable energy production is targeted to be increased substantially, hence the future CHP plants can be assumed to be most probably biomass-fired. Also in literature, CHP production is considered as one of the most potential energy production methods also in the future

(Keirstead et al. 2012; Kohl et al. 2013). In densely populated cities, district heating network can have high connection densities, which makes distribution of district heating more economic and efficient (Helynen et al. 2007).

Integration of biomass upgrading processes with CHP plants is considered to have great potential, since upgraded products have higher energy density and technologies for upgrading are relatively simple and inexpensive. In addition, CHP plants are typically operated on full load only during a short period of time annually, and hence the plant could be utilized for upgrading processes for the rest of the year. (Kohl et al. 2013) In addition to increased operation hours, upgrading processes also improve the quality of and storability of biomass-based fuels, as stated in chapter 6. Especially storability can be an important factor in urban energy systems in the future if more fluctuating energy production capacity will increase significantly and the need for energy storage systems and balancing power grow.

According to a simulation study, wood pellet production has better performance both energetically and environmentally than torrefied pellet and pyrolysis slurry production when integrated to an existing CHP plan. However, the simulation shows that all the three options can extend the operation hours of the plant by 25-28% and increase district heating production by 17.4-21.6%, whereas power output decreases by 0.4-7%. (Kohl et al. 2013) Also various other studies have shown that the integration of upgrading processes has a positive effect on operation hours (Wahlund et al. 2002; Song et al. 2012; Starfelt et al. 2012).

Self-sufficiency in feedstock supply was noticed to be a common aim for the case cities. Therefore, it can be assumed that the role of bioenergy depends on the biomass supply available in the city and surrounding areas. In cities with abundant biomass resources, biomass could be the main fuel for CHP plants, whereas in cities with scarcer resources, co-combustion of biomass with e.g. coal could be used.

A target to increase the energetic utilization of waste was also found in many of analyzed strategies of the cities. Urban harvesting is a potential concept for future cities, and hence the utilization of secondary resources should grow (subchapter 2.3.2). Therefore, all the analyzed technologies that contribute to the utilization of waste materials or waste heat can be considered to have potential in urban environments. MSW can be combusted or co-combusted in fluidized-bed boilers for heat, power and possibly also cooling production.

Biogas production from e.g. sewage sludge or biowaste has also growing potential in urban environments. In addition to the fact that waste materials can be used for biogas production, existing gas networks in many cities makes distribution and storage of biogas feasible. Especially storability is an important feature if significantly more fluctuating energy production capacity, such as wind or solar power, will be installed in cities.

There are also many untapped possibilities for heat recovery in cities. Waste heat is available for example in waste water and in industrial and energy production plants. Especially development of ORC technology can contribute to more efficient utilization of waste heat. In addition, waste heat can be used for district cooling systems and low-temperature district heating. Waste heat recovery is not only related to bioenergy, but it can be utilized also in bioenergy production plants for increasing the efficiency of processes.

Applicability of transport biofuel production to urban environments depends heavily on the used feedstock. If the feedstock is waste-based, for example if waste oils are used for biodiesel production or industrial and municipal wastes for bioethanol production, the production plants might be located in cities. Great amounts of waste are formed in cities, and short distances to reprocessing plants makes the production chain more efficient. In other cases, transport biofuel production may occur outside the city areas. Even in cases when biofuels must be imported to cities from other areas, distribution of transport biofuels may start growing first in cities, where the number of vehicles is great.

8 CONCLUSIONS

There are several factors that are expected to change city structures in the future: population numbers are assumed to continue growing, GHG emissions should be reduced and resources utilized in a sustainable way. Transition towards sustainable and low-carbon cities has already started and various projects have been implemented. Political framework on municipal, national and EU-level was noticed to be one of the most crucial factors for development of urban energy systems.

The EU has set binding targets for its Member States for the reduction of GHG emissions and for increasing energy production from renewable sources. The Member States were also obliged to draw up NREAPs, where measures for reaching the targets are defined. According to the NREAPs, Finland aims at increasing usage of bioenergy in the electricity, heat and transport sectors in total by 40.4 % in 2010-2020. The corresponding percentage for Germany is 36.5%. The bioenergy targets on national level are significant, and because a great share of energy consumption occurs in cities, the role of bioenergy can be assumed to grow also in cities.

The selected group of the ten case cities was aimed to be a comprehensive sample of forerunner cities in Finland and Germany. Although most of the cities were assumed to have a reputation of being ambitious in environmental issues, the current energy production mixes were noticed to be to a great extent based on utilization of fossil fuels in all other cities except Joensuu. Electricity consumption per capita was noticed to be smaller in the German cities than in the Finnish cities. At least colder climate, electrical heating and lower population densities increase the electricity consumption in the Finnish cities.

The review of energy-related documents of the ten case cities from Finland and Germany revealed that the targeted development of energy systems in the case cities was to a great extent based on the renewable energy, energy saving and CO_2 emission reduction targets of the EU. However, some of the cities had set themselves higher targets. The scope of the strategies was dependent on what kinds of actors were involved in the strategy process. In cities with private energy companies and little co-operation between the city council and the local energy company, targets were often mainly limited to energy consumption reductions in municipal buildings and municipal actions as well as information campaigns. Instead, in cities with municipal energy companies or close co-operation between the city and the local energy companies, energy and climate strategies often included concrete measures such as construction of new power plants or distribution infrastructure.

The core target in most of the analyzed strategies was noticed to be CO_2 emission reduction, while improved energy efficiency and renewable energy production were seen as tools for emission reductions. Therefore, for example, the attractiveness of additional utilization of bioenergy depends on how the carbon neutrality of bioenergy usage is defined. Clear common preferences in renewable energy production technologies were not identified. Instead, it can be summarized that the case cities were mainly promoting a wide variety of renewable energy technologies in order to fully exploit all local resources.

Most popular bioenergy-related applications in the cities' strategies were related to utilization of biofuels, biogas production or distribution via gas network, energetic utilization of waste and small-scale heating systems. Decentralized solutions, especially small-scale heating systems and CHP production, were among the most popular targets. However, also centralized CHP production and district heating were planned to be promoted. Since the current plants are mainly fossil fuel-fired, it can be assumed that utilization of bioenergy is planned also for centralized energy production as a partial substitute for usage of fossil fuels.

The specificity of bioenergy-related targets was noticed to be low and hence it is difficult to evaluate the future role of bioenergy based on the strategies. Nevertheless, there were high renewable energy production targets and also the role of bioenergy was planned to be significant at least on the national level. As a result, it can be assumed that the circumstances are favourable for introduction of modern bioenergy technologies also in cities.

Crucial factors for suitability of bioenergy technologies to urban environments are especially feedstock supply and efficiency. Desire for closed-loop systems and scarcity of resources makes energetic utilization of waste more and more attractive. MSW can be used for power, heat and cooling production e.g. by combustion in fluidized-bed boilers. Other potential technologies include co-combustion, pyrolysis and gasification.

Efficiency of centralized energy production is targeted to be risen. In addition, densely-populated city areas offer possibilities for efficient distribution of district heating and district cooling, and therefore CHP or CCHP production could provide the base load heat for the cities. Selection of the optimal fuel for CHP production depends on available local feedstocks. Biomass and MSW can be used either as the main fuels or co-combusted with other fuels.

Biomass upgrading processes are assumed to contribute to the overcoming of many barriers for the usage of biomass. Pelletising, pyrolysis and torrefaction partly solve storage issues, improve the quality of fuel as well as the operation parameters of plants. Therefore, the upgrading processes can be expected to become increasingly important parts of urban energy systems if bioenergy is produced in large-scale units.

According to the analyzed national and municipal strategies, more wind and solar energy capacity will be constructed in the upcoming years. Wind and solar energy production amounts depend heavily on weather conditions, which means that the need for balancing power and heat will increase. Development of smart cities can contribute to keeping the balance between demand and supply in energy systems, but also bioenergy has potential to grow in importance. Upgraded biomass has better characteristics for storing, and hence upgraded biomass could be used as a back-up and balancing fuel. Also biogas has great potential, since it can be used for power, heat and cooling production and also as transport fuel, and it can be rather easily stored e.g. in gas networks.

The analyzed strategy documents describe urban energy system development only from one perspective. Municipalities have only limited decision power over energy-related issues and also the interests of municipalities may change as a consequence of changes of upper-level decision-making bodies or policies. Also, other actors, such as energy companies and developers of technologies, affect the development of urban energy systems.

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APPENDIX 1: RENEWABLE ENERGY TARGETS FOR THE EU'S MEMBER STATES

(Directive 2009/28/EC.2009)

Country	Share of energy from renewable sources in gross final consumption of energy 2005 (%)	Target for share of energy from renewable sources in gross final consumption of energy 2020 (%)
Belgium	2.2	13.0
Bulgaria	9.4	16.0
Czech Republic	6.1	13.0
Denmark	17.0	30.0
Germany	5.8	18.0
Estonia	18.0	25.0
Ireland	3.1	16.0
Greece	6.9	18.0
Spain	8.7	20.0
France	10.3	23.0
Italy	5.2	17.0
Cyprus	2.9	13.0
Latvia	32.6	40.0
Lithuania	15.0	23.0
Luxembourg	0.9	11.0
Hungary	4.3	13.0
Malta	0.0	10.0
Netherlands	2.4	14.0
Austria	23.3	34.0
Poland	7.2	15.0
Portugal	20.5	31.0
Romania	17.8	24.0
Slovenia	16.0	25.0
Slovak Republic	6.7	14.0
Finland	28.5	38.0
Sweden	39.8	49.0
United Kingdom	1.3	15.0

APPENDIX 2: ESTIMATED TOTAL AMOUNT OF EACH RENEWABLE ENERGY TECHNOLOGY IN ELECTRICITY PRODUCTION IN FINLAND IN 2005-2020 ACCORDING TO NREAP

(Ministry of Employment and the Economy 2010)

	Installed electricity generation capacity			Gross electricity generation		
Energy source	**2005 (MW)**	**2015 (MW)**	**2020 (MW)**	**2005 (GWh)**	**2015 (GWh)**	**2020 (GWh)**
Hydro	3 040	3 050	3 100	13 910	14 210	14 410
Geothermal	0	0	0	0	0	0
Solar	0	0	10	0	0	0
Tide,wave ocean	0	10	10	0	0	0
Wind	80	670	2 500	150	1 520	6 090
Biomass	2 140	2 200	2 920	9 660	9 880	12 910
solid	N/A	N/A	N/A	9 640	5 300	7 860
biogas	N/A	N/A	N/A	20	50	270
bio liquids	N/A	N/A	N/A	included in solid biomass	4 530	4 780
Total	5 260	5 940	8 540	23 730	25 620	33 420
of which in CHP	2 030	2 080	2 760	8 480	9 430	12 340

APPENDIX 3: ESTIMATED TOTAL AMOUNT OF EACH RENEWABLE ENERGY TECHNOLOGY IN ELECTRICITY PRODUCTION IN GERMANY IN 2005-2020 ACCORDING TO NREAP

(Federal Republic of Germany 2010)

	Installed electricity generation capacity			Gross electricity generation		
Energy source	**2005 (MW)**	**2015 (MW)**	**2020 (MW)**	**2005 (GWh)**	**2015 (GWh)**	**2020 (GWh)**
Hydro	4 329	4 165	4 309	19 687	19 000	20 000
Geothermal	0	79	298	0	377	1 654
Solar	1 980	34 279	51 753	1 282	26 161	41 389
Tide,wave ocean	0	0	0	0	0	0
Wind	18 415	36 647	45 750	26 658	69 994	104 435
Biomass	3 174	7 721	8 825	14 025	42 090	49 457
solid	2 427	4 358	4 792	10 044	21 695	24 569
biogas	693	3 126	3 796	3 652	18 946	23 438
bio liquids	54	237	237	329	1 450	1 450
Total	27 898	82 891	110 934	61 653	157 623	216 935
of which in CHP	N/A	2 250	3 765	N/A	11 937	20 791