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Future city energy systems
Deliverable 3.1.1

Sustainable Bioenergy
Solutions for Tomorrow

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Summary

The percentage of people living in urban areas is expected to continue growing and in order to create sustainable cities, energy systems need to be modernized. Political framework was noticed to be one of the most important factors for the development of energy systems in addition to e.g. co-operation of various actors and technological innovations. European Union -level targets, national energy strategies as well as strategies of selected case cities include significant aims for increasing energy production from renewable sources and for reduction of greenhouse gas emissions. Both case countries, Finland and Germany, have allocated a great share of the increases in renewable energy production to the production of bioenergy.

Analyzed municipal climate and energy strategy documents were noticed to be to a great extent based on upper-level targets, although the scope and specificity of plans varies. The ultimate target is to reduce greenhouse gas emissions and a great variety of technologies and measures that contribute to the reduction, including bioenergy-related projects, are planned. Most of the selected case cities from Finland and Germany have a reputation of being forerunners in introduction of modern energy technologies and some of the cities have targets for renewable energy production and reduction of greenhouse gas emission that are set higher than the national level. Especially the desire to achieve or maintain a reputation of being a forerunner city by introducing eco-friendly and low-carbon strategies was noticed to be an important driver for setting high targets.

Increasing the utilization of bioenergy is a common aim for all the case cities. Often mentioned bioenergy technology routes are related to e.g. transport biofuels, centralized and decentralized CHP production and small-scale heating systems. In some of the documents, concrete projects for e.g. construction of new bioenergy plants are described, but most cities have only rather general plans for additional bioenergy production. Although bioenergy production is planned to be increased in all the case cities, bioenergy is expected to have only a supporting role in the total energy production mix of most of the cities, e.g. as a heating method in sparsely populated areas.

Bioenergy is planned to be produced in many of the cities in decentralized applications, but otherwise energy production is expected to remain mainly centralized. In all the analyzed documents, a great variety of renewable energy production technologies and energy saving measures are mentioned, although also some clear focus areas could be identified.

Reducing energy consumption is seen as an effective way of cutting CO_2 emissions and therefore improved energy efficiency is listed as one of the key targets in the analyzed strategies. However, cities have only limited possibilities to reduce the total energy consumption of the whole city, and hence most of the energy saving targets are related to municipal buildings and actions.

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Contents

1 Introduction

The importance of cities is growing since the share of urban population is increasing both worldwide and in the EU. In addition to population growth, also national and international climate and energy targets accelerate the transition of urban energy systems. City areas have typically high population density which offers possibilities for unique solutions of energy flows and supply of various energy forms.

Many changes that affect the need for various forms of energy are expected to occur in the upcoming decade. New buildings are constructed according to higher energy efficiency standards and also old buildings are energetic renovated. As a result, demand for heating energy per area is decreasing. In addition, modern heating methods such as heat pumps and solar thermal systems are becoming more common. Energy efficiency and energy recovery are promoted also in other processes and services.

Smart systems are being developed and implemented especially in the energy sector. Emission reduction targets create pressure to implement for example wind and solar power capacity to replace centralized fossil fuel –based power production. Decentralized production and fluctuating production rate create need for new kinds of control and energy storage systems. Even the transportation sector is under a major shift since the increasing number of electric vehicles implies need for charging infrastructure and sufficient power supply.

The aim of this paper is to study the development of urban energy systems and to evaluate the need for various forms of energy. In order to obtain a realistic vision, strategies of ten selected case cities from Finland and Germany are analyzed. When selecting the case cities, forerunner cities are in the focus and also cities from different parts of the countries are searched. Most of the case cities are supposed to have a high population number but also some smaller cities will be analyzed in order to find alternative solutions. The aim is to identify common development trends and find forerunner concepts.

Firstly, energy targets and strategies of national and EU level are described. Characteristics of urban energy demand and energy system development are presented. Secondly, features of case cities are analyzed. Population forecasts and population densities of case cities are presented and current energy production units, energy sources and other existing energy infrastructure are described. Statistics of current energy consumption and prognosis of development of energy consumption are analyzed.

Energy and climate strategies of the case cities are described and analyzed. Also other relevant reports on development of energy systems are presented. Especially the role of bioenergy and waste-to-energy systems is in the focus. Lastly, common features of energy system development of the case cities are summarized and cities are classified according to distinguishing factors.

2 Political and legislative framework of energy system transition

Energy is considered as a vital resource for modern societies. 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 shortly described in this chapter. It shall be noticed, that new policies may be adopted and hence the current framework may be changed.

2.1 Energy related regulations and targets of the European Union

The European Union has defined strategies for the development of its energy sector. Binding targets for the year 2020 are set in the Third energy package established in 2007. (Directive 2009/28/EC)

The latest update in 2014 is the policy framework for climate and energy in the period from 2020 to 2030. 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. New numerical targets are to reduce greenhouse gas emission by 40% compared to 1990 and to increase the share of renewable energy sources in final energy consumption to at least 27%. Contrary to the targets of the Third energy package, the targets of the latest policy are defined only at EU level and not separately for each member state. (European Commission 2014)

The European Union has set a target for increasing the share of energy from renewable energy sources in overall final gross energy consumption to 20 % by 2020. The target is defined in directive 2009/28/EC. Furthermore, the directive includes a goal for transport sector to reach a 10 % share of renewable energy in energy consumption. In addition, the directive obliges greenhouse gas emissions to be reduced by 20% compared to the level of 1990 by the year 2020. (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 set 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 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)

On the contrary, the minimum target of 10 % in the transport sector is the same 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, Member States that are unable to produce the required amount of biofuels in 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 where they define separate 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 fundamental purpose of the roadmap is to provide information on measures that assist on cutting the greenhouse gas emissions by 80% compared to the levels in 1990 by 2050. 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 Council 2011)

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

The most remarkable documents defining national energy and climate policies of Finland are the Long-term Climate and Energy Strategy and National Renewable Energy Action Plan. The Finnish Government has lined out detailed targets and measures for promoting the use of renewable energies 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, the target for the share of renewable energy in final gross energy consumption is 38 % as 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 energy used in the transport sector produced from renewable energy sources, Finland aims at 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 2.1). The results of the calculation process 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 started before 2013, decisions of principle of the parliament about nuclear energy and alignments of the government about the Renewable Energy Action Plan from 2010. In the elaborated basic scenario, also additional measures defined in the update of the Climate and Energy Strategy from 2013 are taken into account. The target in the Long-term Climate and Energy Strategy is to adopt new measures to limit the increase in energy consumption and thus consume not more than 310 TWh in 2020.

Scenarios from 2008 and 2013 are not perfectly comparable since the calculation methods and statistics have changed. (Ministry of Employment and the Economy 2013)

Table 2.1. *Energy scenarios of Finland according to Long-term Energy and Climate Strategy. (Ministry of Employment and the Economy 2013)*

	Statistics	Basic scenario from 2013	Elaborated basic scenario from 2013	Target scenario from 2008
	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 CO2-equivalent	75	65	63	
Sectoral electricity consumption, TWh				
Industry and construction	42	47	48	56
of which pulp and paper industry	20	21	21	
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

The National Renewable Energy Action Plan (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 and prospective measures and reforms. (Ministry of Employment and the Economy 2010)

According to NREAP, the wind power production will rise from 150 GWh in 2005 to 6000 GWh by 2020. The increase is promoted by feed-in-tariffs and an annual sum of 1.5 million euros earmarked for supporting 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 12900 GWh in 2020, whereas the overall generation in 2005 was 9700 GWh. 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 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 estimates to have the potential to cover approximately 15 % of the target if new capacity will be constructed. (Ministry of Employment and the Economy 2010)

The NREAP contains information about how Finland's energy consumption will develop in the electricity, heating and cooling and transport sector until 2020 (Table 2). The estimates are prepared 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 2.2*. Expected gross final energy consumption in Finland in 2010-2020 (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

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

The most significant documents that define the energy policy of Germany include Energy concept, National Renewable Energy Action Plan and regional strategies of the federal states. Other important documents are for example Renewable Energy Sources Act and Renewable Heat Act that contain definition of support measures for renewable energy production.

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 an 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 reaching of the targets defined in 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 2.3). (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010.2011)

Table 2.3. *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 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 percentual reduction in energy consumption in the transport sector is expected to be 10% by 2020 and 40% by 2050. Furthermore, there are targeted to be 1 million electrical vehicles in use in 2020 and 6 million in 2030. (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2010, 2011)

The National Renewable Energy Action Plan 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 national action plan: 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, the gross final consumption of energy will decrease remarkably compared to base year 2005 (Table 2.4). The most substantial decrease is expected to occur in the heating and cooling sector. (Federal Republic of Germany 2010)

Table 2.4. *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. Sectoral figures are: 38.6 % for the electricity sector, 15.5 % for the heating sector and 13.2 % for the transport sector. (Federal Republic of Germany 2010)

In order to achieve a 38.6 % share of final energy consumption produced from renewable energy sources, there should be approximately an additional 112 TWh renewable energy in the electricity sector compared to 2010 (Appendix 3). The greatest 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. The share of offshore wind power is estimated to be 31.5 TWh. The second biggest increase is planned for photovoltaic. According to the national action plan, 41.1 TWh of electricity will be produced with solar power, which is 31.9 TWh more than in 2010. The increase in the use of biomass is estimated to be 16.7 TWh resulting in 49.5 TWh annually in 2020. (Federal Republic of Germany 2010)

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 quantity 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 is. 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)

Renewable Heat Act (EEG-Wärme) for 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, the 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 for geothermal energy and heat pumps the percentage value 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. Breakage of the law can lead to fines. Production of renewable energy –based heat was supported by the state with up to 500 million euros per year in 2009-2012. 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 Rheinland-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)

2.4 Summary of energy and climate targets in Finland and Germany

The strategies of both Finland and Germany for the time period until 2020 are based on 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 orders only the targeted share of renewables in energy consumption, Member States can consider 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 defined in the NREAP (Table 2.5) (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 2.5: *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)*

	2005		2015		2020		Change 2005-2020	
	Finland (GWh)	Germany (GWh)	Finland (GWh)	Germany (GWh)	Finland (GWh)	Germany (GWh)	Finland (%)	Germany (%)
Hydropower	13910	19687	14210	19000	14410	20000	3,6	1,6
Geothermal energy	0	0,2	0	377	0	1654		826900,0
Solar Energy	0	1282	0	26161	0	41389		3128,5
Wind Energy	150	26658	1520	69994	6090	104435	3960,0	291,8
Biomass	9660	14025	9880	42090	12910	49457	33,6	252,6
Total	23730	61653	25620	157623	33420	216935	40,8	251,9

The most notable differences lie in solar energy. Finland has no significant plans for constructing solar energy plants, whereas Germany aims at increasing the annual production by more than 40000 GWh. The most obvious reason for the difference is Germany's location; in southern Germany the intensity of solar radiation is a lot more favourable for efficient solar energy production than in Finland (Federal Republic of Germany 2010, Ministry of Employment and the Economy 2010)

Both countries are planning a great increase in wind power production: Germany intends to increase the production by approximately 78000 GWh and Finland by 6000 GWh. 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 meaning especially due to strong pulp and paper industry. The increase of 3250 GWh has 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 by 2020 the amount of annually produced biomass based electricity is expected to have grown by 35000 GWh. (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 2.6). 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 2.6: *The 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 (GWh)	2015 (GWh)	2020 (GWh)	Change 2005-2020 (%)
Heating and cooling	64988	73269	85411	31,4
Electricity	23645	25780	33543	41,9
Transport	0	5722	9490	-
Total	87956	103960	124494	41,5
Germany				
Heating and cooling	89686	144528	178041	99
Electricity	61464	163802	236252	284
Transport	24312	42485	79822	228
Total	173182	343725	482336	179

The sum of all produced renewable energy is expected to rise by 36 500 GWh in Finland and by 309 000 GWh in Germany. The increase is significant in all sectors, but the greatest in heating and cooling in Finland and in electricity in Germany. (Federal Republic of Germany 2010, Ministry of Employment and the Economy 2010)

The focus of this paper is on bioenergy and therefore plans for utilization of bioenergy are analyzed further. The targeted development for usage of bio liquids, solid biomass and biogas in electricity, heating and cooling and transport is defined in the NREAPs (Tables 2.7 and 2.8). The tables show that 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 2.7: *Targets for increases in biomass, biogas and bio liquid consumption in energy sector in Finland according to the National Renewable Energy Plan* ***(****Ministry of Employment and the Economy 2010)*

	Finland			
	Total	Biomass	Biogas	Bio liquids
2010 (GWh)	68565,7	35447,0	388,9	32729,8
2020 (GWh)	96297,1	53682,2	967,8	41647,1
Change 2010-2020 (%)	40,4	51,4	148,9	27,2

Table 2.8: *Targets for increases in biomass, biogas and bio liquid consumption in energy sector in Germany according to the National Renewable Energy Plan* **(***Federal Republic of Germany 2010)*

	Germany			
	Total	Biomass	Biogas	Bio liquids
2010 (GWh)	179581.8	104909.0	25621.8	49051.0
2020 (GWh)	245166.8	128680.8	45128.0	71358.0
Change 2010-2020 (%)	36.5	22.7	76.1	45.5

3 Future city structures

In Finland, 68% of population lives in urban areas. For Germany the corresponding percentage is 73% and for the whole Europe 71% according to Population Reference Bureau. In the statistics of Population Reference Bureau, each country has defined the term “urban area” on their own or alternatively the definition of the UN is used and therefore there are several different definitions. (Population Reference Bureau) The urbanization is expected to continue in the upcoming decades (VTT 2009 p. 21), which means that new urban areas will be constructed and old infrastructure must be 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 a strong impact on urban energy demand.

3.1 Urban energy demand

Energy is needed in cities for various actions, transport and construction of buildings and infrastructure. Many characteristics of cities affect the demand for energy: population density, public transportation systems, energy-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. If the land area per capita is increased by 100%, the energy demand in the traffic sector is increased by 50%, which means that there is a strong negative correlation between energy use in transport and population density. In addition, city structures affect heavily the energy consumption of the traffic sector. The average commuting distances and locations of shopping and leisure time centers in relation to residential areas define a great share of energy demand in the transport sector. (VTT 2009, p.63-66)

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. Energy consumption is fundamentally caused by individual choices. The 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. (VTT 2009, p.54, 63-66)

Industrial processes are often energy intensive. 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. (VTT 2009, p.69-70) Therefore, industry has often a remarkable effect on cities' energy consumption, but it will be given less attention in this paper.

3.2 Energy system development

Targets for future energy systems are rather similar in all case cities that will be analyzed further in later chapters of this paper– low-emission energy production will be promoted and energy savings are pursued via improved energy efficiency and advanced technologies. However, various kinds of city structures can allow sustainable urban living.

Alternative development paths for a sustainable and low-energy city are studied in an article Backcasting images of the future city – Time and space for sustainable development in Stockholm by Höjer, Gullberg and Pettersson. The paper introduces a backcasting study on the development of Stockholm until 2050 assuming a 60% reduction of energy consumption per capita in 50 years. In the study all energy consumption is allocated to individuals and six scenarios are created by varying time and space dimension taking into account technological development. (Höjer et al. 2011)

The initial target for reducing energy consumption per capita per 60% is derived from the target of the Intergovernmental Panel on Climate Change to limit the increase in the Earth's average temperature to two degrees. The required reduction in GHG emissions indicates that the global energy consumption should be approximately 130 PWh. Considering global population forecasts and assuming that the Swedes should not consumer more energy than the global average, the energy consumption reduction per capita can be estimated to be 60% until 2050. (Höjer et al. 2011)

In all the scenarios, the total energy consumption is the same, but its distribution varies. The alternative distributions were drawn up using information from workshops and interviews about current energy consumption in households. The characteristics of sustainable life in each scenario are described. Tempo of life is considered as slow or fast and possibilities for city structures are urban cores, suburban centers and low-rise settlements. Urban cores mean dense areas with about 100000 inhabitants and work places. In Stockholm area, there could be for example five urban cores that are corresponding to traditional city centers. Suburban centers rely on a strong city center with good radial connections from housing areas further from the center. The third option is low-rise settlements outside of the inner city where people can have their own gardens.

Improvement in energy efficiency in industry is estimated to be 30% in slow scenarios and 40% in fast scenarios based on historical trends. Development of energy consumption in traffic sector is estimated as in an article How much transport can the climate stand? – Sweden on a sustainable path in 2050 by Åkerman and Höjer (Table 3.1). The greatest improvement in energy efficiency is expected for cars in passenger traffic and for light trucks in goods transport. (Höjer et al. 2011)

Table 3.1: *Estimate on energy demand for transport in 2050 (Åkerman et al. 2006)*

Passenger transport	kWh/passenger-km	Improvement (%)
Car (<100 km)	0,2	75
Electric car	0,1	
Small electric car	0,07	
Car (>100 km)	0,12	65
Bus (<100 km)	0,09	60
Bus (>100 km)	0,07	40
Ferry	0,42	30
Rapid ferry	1,3	30
Rail (<100 km)	0,08	50
Rail (>100 km)	0,05	50
Air	0,32	45
Goods transport	kWh/tonne-km	Improvement (%)
Truck (<100km)	0,42	40
Truck (>100km)	0,17	30
Light truck		45
Railroad	0,03	30
Ferry(25%)	0,14	30
Cargo ship	0,04	30
Air freight	1,68	44

Around 75% of the energy efficiency improvement is expected to occur via improvements in technology. The rest is assumed to happen as a consequence of reduction of heated space, stop in increase of housing area, changed cooking and eating habits and decrease in air travel volumes. (Höjer et al. 2011)

Distribution of energy consumption is estimated in TWh separately for five household functions (personal, housing, food, care and support) in six different scenarios according to Höjer et al (2011). Energy consumption is particularly big in personal activities in both of the urban cores scenarios. Instead, energy consumption of housing is the greatest in low-rise scenarios. (Höjer et al. 2011) It should be noticed from the results, that even though the expected reductions in energy consumption would be reached, the distribution of energy demand of various actions can vary significantly depending on how the city will develop. The distribution of energy demand has an effect e.g. on when the energy is needed and how fluctuating the demand is.

Prerequisites for innovative and sustainable city development are studied for instance in an article “Cities as development drivers: from waste problems to energy recovery and climate change mitigation” by Johnson et al. (2011). In the paper, Aalborg in Denmark and Malmö in Sweden are used as case cities where sustainable development and innovation process have been successfully implemented in the field of waste management. According to the article, the development process in the case cities required high capital investments, development of new institutes and technological and organizational knowledge. Various political, institutional, technological and organizational factors have interacted and several types of actors have been working in new areas to enable the successful development process. A crucial factor for the development of new knowledge and competence is stated to be strong interaction and co-operation between the city and research institutes. (Johnson et al. 2011)

Public organizations, policy makers as well as engineering consultants created the technical innovations in the case studies in co-operation. Driving forces for the development process were public awareness about environmental, climate and energy related issues, pressure from public organizations and from city administration and in general increasing need for flexible solutions for environmental problems. (Johnson et al. 2011)

Municipal environmental departments have taken a central role in environmental decision-making both in Aalborg and in Malmö. Also new types of actors, such as unions of several municipalities, have started to contribute to the technical and political implementation processes. Some of the new private actors have benefitted the investing in waste management and developed new technologies even for export. (Johnson et al. 2011)

New measuring, simulating and modeling tools such as mass balances, cost benefit analysis and lifecycle assessments were developed for the scenario work. Improved tools contributed to enhanced scenarios, better interaction between stakeholders and advanced decision making processes. New environmental legislation and bureaucracies and improved framework for innovations and investments are said to have had a great effect on the development of waste management sector in the case cities. Introduction of new visions and long-term goals was also argued to have contributed to the innovation process. (Johnson et al. 2011).

Promotion of certain technologies can also occur via taxes, subsidies and regulations. A relatively high political independence of municipalities from the national government simplifies the establishment of suitable restrictions and fees, although national legislation should also be in line with the policies of municipalities. Additionally, EU-level policies and regulations, especially binding targets, strongly supported the development in the cases of Aalborg and Malmö. (Johnson et al. 2011).

3.3 Low-carbon and carbon neutral cities

One significant target that is common for many cities is the aim to become a low-carbon or carbon free city after some decades. However, the definition' low-carbon city' is not unambiguously defined. In an article Evaluation of a Low Carbon city: Method and Application by Su et al., several popular 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)

Carbon neutrality is a popular target for many cities also outside of Europe. For example Masdar city in Abu Dhabi is argued to be the first carbon-neutral and zero-waste city in the world. Construction of the city was started in 2006 and it is planned to be completed in 2016. The initiative for the carbon-neutral city came from the government of Abu Dhabi as a part of a regional economic development program. Masdar city is planned for around 40000 residents and 50000 daily commuters, and therefore it is stated to be the biggest carbon-neutral city in the world according to the article, not the first one in general. However, the aim for having a certain population number and number of companies operating in the city is argued to be rather optimistic. Wider interest among companies for investing in the city and starting business there would require more ambitious political framework on regional and national level and as a consequence regional demand. To create the required regional demand, Abu Dhabi set a target of having 7% of the total power generation capacity in the emirate based on renewable energy sources by 2020. (Reiche 2010)

Smaller carbon-neutral towns have already been constructed in many countries. In Germany, the first bioenergy village, Jühnde, with 800 inhabitants, was introduced in Lower Saxony in 2006. The construction of the energy system was partly funded by the German government and the EU. 70% of the inhabitants of the village also participated in funding of the new energy system. Energy production in the village is mainly based on a biogas facility. Biogas is produced by fermentation from liquid manure and silage of energy crops. Production gas is utilized in a 700 kWe and 750 kWth CHP plant. The biogas plant generates 5000 MWh of electricity annually and the total heat production from the biogas plant and wood chips boiler is approximately 6500 MWh. Heat is supplied to 70% of the households of the village via a 5.5 km long pipeline. In cold temperatures, local wood is also combusted in a 550 kWth boiler for the heating system. (IEA Bioenergy 2009)

Jühnde is considered as a successful demonstration project on bioenergy. The success factors are said to be suitable infrastructure, biomass production method and social aspects and decisions that are in line with local needs. Is it also stated, that comprehensive feasibility studies and business plans are crucial for similar projects. Co-operation with local biomass providers, in Jühnde's case farmers and foresters, is also important to ensure biomass supply with stable prices. (IEA Bioenergy 2009) Although Jühnde is a small village, the experiences for the demonstration project can be beneficial for introduction of bigger bioenergy towns.

3.4 Significant programs on municipal energy systems

The European Commission initiated the "Covenant of Mayors" after the establishment of the Third Energy package in 2008. The "Covenant of Mayors" is a movement that supports and promotes regional actors in the Member States in their actions in climate protection. The aim is to meet or even exceed the targeted 20% reduction in CO_2 emissions by 2020. All the cities that participate in the movement submit a sustainable energy action plan where measures for reaching the objectives are described. Furthermore, special actions performed are listed as benchmarks of excellence. Of the case cities, Tampere, Espoo, Turku, Berlin, Hamburg, Munich and Freiburg im Breisgau have joined the Covenant of Mayors. CO_2 reduction targets of case cities in Covenant of Mayors are: Espoo 28%, Tampere 30%, Turku 20%, Berlin 40%, Freiburg im Breisgau 20%, Hamburg 40% and Munich 47%. The German cities have more ambitious targets than the Finnish ones, but on the other hand, if the starting level is high, great percentage reductions are easier to make. (Covenant of Mayors 2014)

Ministry of Employment and the Economy of Finland administers several programs on energy efficiency. In the municipal sector, there are two programs for the time period 2008-2016. Municipalities with more than 5000 inhabitants and federations of municipalities whose energy consumption is at least 5000 MWh/a can sign a bilateral energy efficiency agreement with the Ministry. Smaller municipalities can join an energy efficiency program administrated by Motiva Oy. The core target of both agreements is to reduce energy consumption by 9% during the stated time period. All the Finnish case cities have signed an energy efficiency agreement with the Ministry of Employment and the Economy. (Ministry of Employment and the Economy 2014)

All the German case cities, Berlin, Freiburg im Breisgau, Hamburg, Munich and Wuppertal are members of the "Climate Alliance", an European network of 1600 cities and municipalities from 24 European countries. The 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

Most major cities both in Finland and Germany have established their own climate and energy strategies that rest upon corresponding national and EU-level guidelines. Many of the strategies include also additional information about the estimated growing rate of population, renovation of the building stock and development of the industry sector, among other things.

4.1 Selection of the case cities

To evaluate the future of Finnish and German cities, five cities were selected from both countries. Selection criterion for case cities was that the cities were supposed to be located in different parts of the countries and have a relatively high number of inhabitants. For comparison cities with various population numbers were selected. The focus is on forerunner cities that are most likely to adopt new energy technologies among the first ones.

The Finnish case cities are: Espoo, Tampere, Vaasa, Turku and Joensuu. Espoo is the second biggest city of Finland and a part of the capital region. The population of Espoo is 260 753. (Tilastokeskus 2013) Espoo has established a climate strategy for a time period until 2030 together with the whole capital region. (Anderson et al. 2007) In addition, Espoo published its own review of renewable energy in 2012. (Raunio et al. 2012)

Tampere is located in western Finland, in Pirkanmaa, and has a population of 215 168. (Tilastokeskus 2013) Tampere has formulated a climate strategy for a period up to 2020 together with 7 neighboring towns in 2010. A new climate and energy strategy for the province of Pirkanmaa was published in 2014. (Pirkanmaan liitto 2014)

Turku is a harbor city in the south-west with 178 630 inhabitants. (Tilastokeskus 2013) The climate and energy strategies of Turku were published in 2011. The strategies cover the whole region of Southwest Finland that contains 28 municipalities and 468 936 inhabitants. (Varsinais-Suomen liitto 2010) The climate strategy was drawn up by the Center for Economic Development, Transport and the Environment (Uitamo 2011) and the energy strategy was drawn up by the Service Center for Sustainable Development and Energy of Southwest Finland (Vieno 2011).

Vaasa has a population of 65 173 (Tilastokeskus 2013) and it is located in the west coast of Finland. Vaasa participates in Ostrobothnia Region's climate strategy adopted by the provincial government in 2012. The strategy is drawn up by Technology Center Oy Merinova Ab and the Regional Council of Ostrobothnia. (Wasberg et al. 2012)

Joensuu is located in eastern Finland and has 73 758 inhabitants. (Tilastokeskus 2013) Joensuu's climate plan is defined in Joensuu metropolitan area's climate strategy from the year 2009. First update of the strategy was published in 2014 under the name Climate Program of Joensuu. (City of Joensuu 2014)

The selected case cities from Germany are: Munich, Hamburg, Berlin, Wuppertal and Freiburg im Breisgau. Munich is the capital of Bavaria and the third largest city of Germany with a population of 1 378 176 (Destatis 2013). Munich has drawn up a climate plan in 2013 together with five neighbouring towns: Baierbrunn, Gräfelfing, Kirchheim bei München, Schäftlarn and Unterföhring. (Karg et al. 2013) The state of Bavaria has also a common energy concept from the year 2011. (Bayerische Staatsregierung 2011) "Perspective München" is the city development concept of Munich. The concept consists of strategic guidelines, thematic guidelines and projects and terms of reference. One of the thematic guidelines is about climate change and climate protection. The latest update of the guideline is from 2011. (Landeshauptstad München 2010)

Hamburg is located in the north of Germany and it is an important harbor city. Hamburg has a population of 1 798 836. (Destatis 2013) Energy related targets and strategies for Hamburg are defined in several documents. Guidelines for development until 2050 are described in the "Masterplan Klimaschutz" that also contains a description of agreements of co-operation with the local energy companies, E.On Hanse Ag and Vattenfall Ag. (Bürgerschaft der Freien und Hansestadt Hamburg 2013) Furthermore, the Senate of Hamburg has an Environmental program for 2012-2017. (City of Hamburg 2012)

Berlin is the capital of Germany and the biggest city of the country with 3 501 872 inhabitants (Destatis 2013). Berlin is an inland city and a federal state in the north-eastern Germany. Berliner Energieagentur, the energy agency of Berlin, draw up an energy supply strategy called Energy Concept 2020 for the city in 2011 mandated by the Senate Department for Economics, Technology and Women's Issues. (Suck et al. 2011)

Freiburg im Breisgau is a town in Baden-Württemberg with 229 144 inhabitants (Destatis 2013). The Institute for Applied Ecology "Öko-Institut e.V." has formulated a climate strategy for the city of Freiburg in 2007. (Timpe et al. 2007) In 2011, the Institute of Applied Ecology published a report of a study called "Freiburg 2050 - Auf dem Weg zur Klimaneutralität". The aim of the study is to investigate, what measures are needed to minimize the greenhouse gas emissions. A strategy for the time period until 2050 is presented. (Kenkmann et al. 2011)

Wuppertal belongs to the state of North Rhine-Westphalia and to the industry area of Ruhr and it has 349 470 inhabitants. (Destatis 2013) 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 public economy. The city council of Wuppertal established a program called “Energy efficiency and climate protection in Wuppertal- strategy 2009-2020” in 2009. The program contains more than 100 measures for energy saving and climate protection. (Brendel 2009) Another document that describes the potential development of the city’s energy system is a special study called “Low Carbon city Wuppertal 2050” from 2012 by Wuppertal Institute. The aim of the study was to investigate, what kind of impact various measures and instruments have on the greenhouse gas emission levels and resource protection and to come up with new solutions. (Reutter et al. 2012)

4.2 Population densities and forecasts

The city of Espoo has prepared a regional population forecasts for the years 2013-2023. According to the forecast, the population growing rate would be over 1.5% in 2013-2015, approximately 1.3% in 2016-2019 and 1.2% starting from 2021. (Espoon kaupunki 2014) The latest long-time population forecast for Espoo is from the year 2012. The baseline of the forecast estimates that the population will grow by 75 000 by 2035 and by 115 000 by 2050. (Laakso 2013)

Tampere region is one of Finland’s fastest growing regions. For structure planning, it is estimated that the population will grow by 90000 inhabitants by 2030. In addition to population growth, reduction of housing density causes a need for 60000 more apartments. The increase in workplaces is estimated to be 62000. (Tampereen kaupunkiseutu 2010, p.57)

Vaasa has published its own population forecast in November 2013. According to the forecast, the number of inhabitants would be 76 500 in 2030 which means that the population should grow by 600 inhabitants annually. (Kommonen 2013) The Statistics Finland has published a more moderate forecast with a population of 68 435 in 2030. (Tilastokeskus 2012)

According to Statistics Finland’s forecast from 2011, the population of Joensuu would be 76 149 in 2020, 77 878 in 2030 and 78 513 in 2040. (Tilastokeskus 2012) The population forecast of Statistics Finland for Turku estimates the number of inhabitants to be 185 500 in 2020, 191 503 in 2030 and 196 236 in 2040. (Tilastokeskus 2012)

The Statistical Office for Berlin-Brandenburg and the City Council City Development and Environment compiled a population forecast for Berlin for the years 2011-2030 in 2012. The forecast contains three variations of population growth: low, middle and high. According to the middle variation, the population number would be 3 623 000 in 2015, 3 698 000 in 2020 and 3 756 000 in 2030. (Senatsverwaltung für Stadtentwicklung und Umwelt 2012)

The latest official population forecast for Hamburg is from the year 2011. The estimate for number of inhabitants in Hamburg in 2020 is 1 842 400 and in 2030 1 853 800. The percentual growth rate would be 3.3% in 2010-2020 and 0.6% in 2020-2030. (Statistische Amt für Hamburg und Schleswig-Holstein 2010)

The Statistical State Office of Baden-Württemberg has created a population forecast for 2015 and 2030 for all municipalities in the state. The estimated population number for Freiburg im

Breisgau is 222 200 in 2015 and 218 900 in 2030. (Statistisches Landesamt Baden-Württemberg 2013) Estimation for 2020 was calculated with linear interpolation to get comparable values with other forecasts.

The city of Munich has established a population forecast in 2011. According to the forecast, the population will increase by 139 000 by 2020 and by 214 000 by 2030 compared to the year 2011. (Landeshaupstadt München 2011, p.7)

Population forecast for Wuppertal can be found in the city of Wuppertal's online statistics database. The forecast for 2020 is 330 421 inhabitants and for 2025 322 429 inhabitants. (Statistik-Datenbank Wuppertal 2007)

To sum up, only Wuppertal and Freiburg im Breisgau have negative population forecasts, whereas the fastest growing cities seem to be Espoo, Munich, Vaasa, Berlin and Tampere (Table 4.1) (note:For the Finnish cities, the forecasted values in the table are all from Statistics Finland's population forecast from the year 2012 for better comparability).

***Table 4.1**. Population forecasts and current number of inhabitants of example cities (Tilastokeskus 2012, Landeshaupstadt München 2011, p.7, Statistische Amt für Hamburg und Schleswig Holstein 2010, Senatsverwaltung für Stadtentwicklung und Umwelt 2012, Statistik-Datenbank Wuppertal 2007)*

	Population			Change [%]	
Town	2011	2020	2030	2013-2020	2020-2030
Espoo	252439	281970	306965	11,7	8,9
Joensuu	73758	76149	77878	3,2	2,3
Tampere	215168	229609	241978	6,7	5,4
Turku	178630	185500	191503	3,8	3,2
Vaasa	60 398	64765	68435	7,2	5,7
Berlin	3 501 872	3698000	3756000	5,6	1,6
Freiburg im Breisgau	229 144	228392	229506	-0,3	0,5
Hamburg	1 798 836	1842400	1853800	2,4	0,6
Munich	1 378 176	1517039	1591968	10,1	4,9
Wuppertal	349 470	330421	-	-5,5	-

Population density was said to affect energy consumption significantly in chapter 2.1. Therefore population densities of the case cities were calculated by dividing population numbers by land areas (Table 4.2). The table shows that the German case cities have clearly bigger population densities than the Finnish case cities.

Table 4.2: *Land areas and population densities of the case cities (Tilastokeskus 2013, Destatis 2012)*

	Land area (km^2)	Population	Population density (1/km^2)
Espoo	312	252439	809
Joensuu	2382	73758	31
Tampere	525	215168	410
Turku	246	178630	726
Vaasa	364	65173	179
Berlin	892	3 501 872	3927
Freiburg im Breisgau	153	229 144	1497
Hamburg	755	1 798 836	2382
Munich	311	1 378 176	4436
Wuppertal	168	349 470	2075

4.3 Current energy infrastructure and production mix

In Espoo, there is one coal and natural gas CHP plant with capacity of 359 MW of electricity and 554 MW of heat. (Fortum 2014) Additionally, there are eight heating plants with total capacity of 697 MW. All heating plants utilize either natural gas or oil as a fuel. (Raunio et al. 2012) In the landfill of 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) The construction of a new biogas plant started in the same location in 2014 with the landfill. The plant is will be based on digestion and it will have the capacity to process 60 000 tonnes of biowaste of which around 44 000 tonnes will be digested. The product gas will be utilized in a gas engine plant with capacities of 1.8 MWe 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 important method and oil and gas the third. (Figures 4.1 and 4.2) 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. (Pääkaupunkiseudun ympäristötieto 2013)

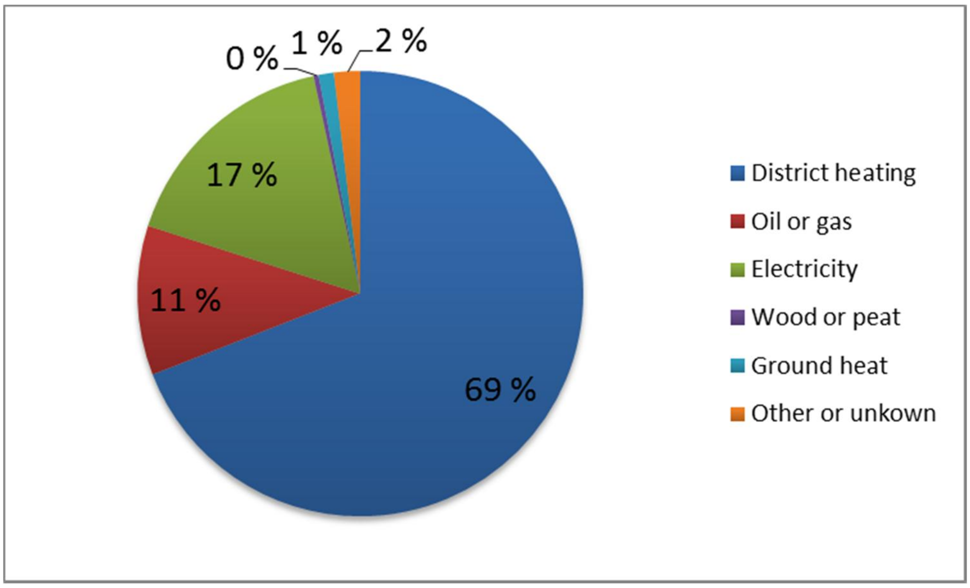

Figure 4.1*: Distribution of heating methods by floor space in Espoo in 2010 (Pääkaupunkiseudun ympäristötieto 2013)*

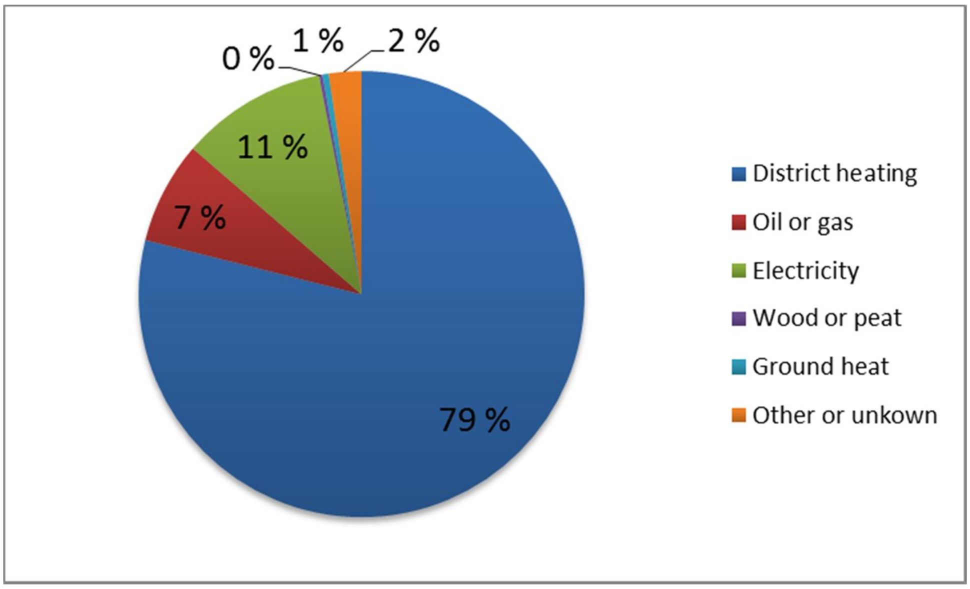

Figure 4.2: *Distribution of heating methods by floor space in the capital area of Finland in 2010 (Pääkaupunkiseudun ympäristötieto 2013)*

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 natural gas plant was modernized to use natural gas in 2000 and has nowadays electrical capacity of 129 MW and heating 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 total length of 50 km and nearly 100 of 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 in Tampere started in 2013.. The plant is based on grate technology and it 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. Combustion temperature will be over 850 °C and the overall efficiency of the process is more than 85% based on the energy content of the fuel. The plant is planned to be operated continuously year round. (Tammervoima 2013) The main component of the waste fuel is non-recyclable communal waste that is collected from the Pirkanmaa region. The region 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. (Aleuehallintovirasto 2013) In February 2014, the municipal energy company of Tampere made an agreement on construction of a new 49.5 MW heating plant with 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)

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 557 MW. (Uitamo 2010) The electricity of the region is produced mainly in Naantali in a coal CHP plant with electrical capacity of 290 MW. (Energiavirasto 2014) District heating system covers the homes of 94 % of the population of the city. (Energiateollisuus 2013) The degree of self-sufficiency was 46 % in 2010. (Varsinais-suomi päästötase 2010)

Joensuu has two hydro power plants with total capacity of 4.8 MW (Energiavirasto 2014) 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. 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 whose main fuel is wood residues. There are also 14 heating plants with total capacity of 225 MW. (Fortum 2014) 57% of the population of Joensuu lives in buildings that are connected to district heating network. (Energiateollisuus 2013)

Vaasa has two CHP plants in Vaskiluoto. One is fuelled with coal and its electrical capacity is 230 MW and heating capacity 175 MW. The other is an oil-fired peak-load power plant with electrical capacity of 160 MW and heating capacity of 175 MW. (Pohjolan Voima 2014) In 2012, a new biomass gasification plant started operating integrated to the coal power plant. The aim was to replace 25-40 % of the coal with local biomass, mostly wood chips. Non-recyclable waste from households and industry are utilized in a waste incineration plant that is located outside the city border of Vaasa. 20 000 kilograms of waste can be combusted in the plant in an hour and the capacities are 13 MW of electricity and 40 MW of heat. Annual energy production 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, biofuels accounted for more than 50% of the total used fuels in the major power plants in Ostrobothnia (Figure 4.3).. (Wasberg et al. 2012) The share of population of the city that lives in buildings connected to district heating network is 80%. (Energiateollisuus 2013)

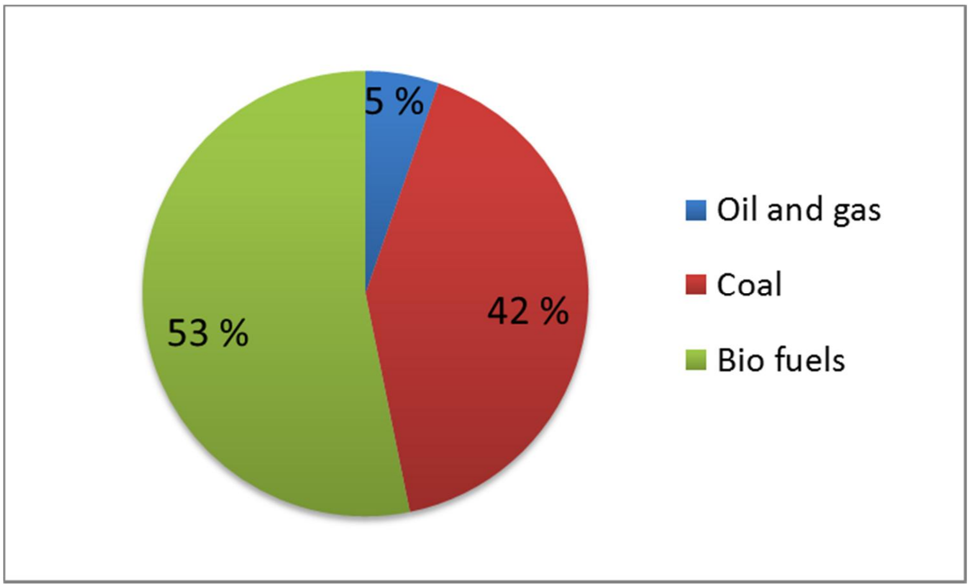

Figure 4.3 *Distribution of used fuels of major power plants in Ostrobothniain 2007 (Wasberg et al. 2012)*

In Berlin and the nearby region, there are several CHP plants that are mostly coal-fired or gas-fired (Table 4.1). (Bundesnetzagentur 2012)

Table 4.1*: 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 500000 tonnes of waste annually and it has been the core of Berlin's waste management since 1967. 2.3 tonnes of high pressure steam can be produced by combusting 1 ton 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 the same location in Ruhleben, a new biogas plant 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. (Suck et al ,p.51)

Approximately 40 % of the demanded electricity in Freiburg im Breisgau is produced in a steam and gas CHP plant with electrical capacity of 60.1 MW. The annual production of the plant is 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 in Freiburg im Breisgau 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 kWe and 7000 kWth 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 million kWh and wind power production 12.9 million kWh, 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)

In Hamburg, the biggest CHP plant has electrical capacity of 321 MW and heating capacity of 814 MW. The main fuels are coal and natural gas. Another CHP plant is a coal plant with electrical capacity of 250 MW and thermal capacity 423 MW. A new coal-fired CHP plant with capacities of 1654 MWe and 420 MWth will start operating in 2014. (Vattenfall 2014) The municipal energy company has 25 solar energy units with total capacity of 25 MW, three small CHP plants with total electrical capacity of 1 MW and heat capacity 10 MW and three wind power parks with total capacity of 7.4 MW. (Hamburg Energie 2014) 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 tons of municipal solid waste is combusted at a 24 MWe and 146 MWth waste incineration plant. (Vattenfall 2014) Yet another waste incineration plant called Stapelfeld processes around 350 000 tonnes of waste annually producing 80 GWh electricity and 230 GWh heat. (EEW Energy from Waste Stapelfeld GmbH 2014) In Bützberg, 70 000 tonnes of biowaste are fermented into 2.5 million m^2 biogas that is refined into methane and distributed via natural gas network. The plant was opened in 2011 and it 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 MWel and 1 MWth CHP plant. The plant started operating in 2006. In addition, 18 MWh of biogas is produced annually from sewage at waste water treatment plant of Hamburg Wasser and supplied into the natural gas network.

(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)

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) There are three CHP plants: one coal plant with electrical capacity of 78 MW and heating capacity of 189 MW and one gas and steam turbine power plant with the capacity of 75 MW of electricity and 80 MW of heat. In addition, there is an oil-fuelled peak-load power plant with electrical capacity of 60 MW. (WSW 2014) Furthermore, there are two CHP power plants Barmen and Elberfeld. Barmen is a gas and steam turbine plant with the capacity of 84 MW of electricity and 110 MW of heat. The main fuel of Elberfeld is coal and it has the capacity of 100 MW of electricity and 201 MW of heat. (WSW 2014) 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 CHP plants in Kohlfurt and Buchenhofen with electrical capacities of 430 kW and 2 MW. In Buchenhofen also waste food is fermented. Wuppertal has high district heating and natural gas network connection rates. There are two major district heating networks that are connected to each other and several smaller zone heating networks. (Brendel 2009)

Stadwerke München (SWM) is the municipal energy company of the city of Munich. SWM operates three CHP plants (Table 4.2), eight heating plants, two small-scale gas CHP plants and six hydropower plants including some pumped-storage plants in Munich. 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. (Stadtwerke München 2014)

Table 4.2. *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

The length of the district heating network in Munich is about 800 km. Approximately 70% of the electricity generated in Munich is produced combined with heat. (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)

As a conclusion, it can be said that almost all the biggest energy production units in the case cities are fossil fuel-fired. Joensuu is the only case city where the biggest power plants are fired with wood and peat. In Vaasa, attempts to replace fossil fuels with biomass have already been made since a biomass gasification unit has been constructed integrated to the coal plant. Turku, Berlin, Hamburg, Munich and Wuppertal have waste incineration plants with significant capacities.

The existing district heating and natural gas networks are important factors for decision making. Natural gas network can be also used for biogas delivery and it is a prerequisite for introduction power-to-gas storage systems. Existing district heating network can be a determining factor when deciding which low-carbon heating systems to implement. According to the German Renewable Heat Act, cities are even allowed to establish connection obligations to district heating network to make its operation and development more profitable, as stated in chapter 2.3.

Analyzing the energy production plants solely inside the city borders is not sufficient, since in many cases significant amount of energy is transferred to cities from the surrounding area. Therefore the net capacities of power plants are listed by energy source for each federal state by the German Bundesnetzagentur (Table 4.3).

***Table 4.3**: Power production capacities the federal states of the case cities by energy source (Bundesnetzagentur 2012)*

	Baden-Württemberg, total installed electrical capacity 17734 MW (%)	Bavaria, total installed electrical capacity 26319 MW(%)	Berlin, total installed electrical capacity 2509 MW (%)	Hamburg, total installed electrical capacity 530 MW (%)	North Rhine-Westphalia, total installed electrical capacity 41245 MW (%)
Waste	1	1	1	5	1
Biomass	5	4	1	8	2
Brown coal	0	0	7	0	26
Gas	6	17	44	27	19
Nuclear energy	15	20	0	0	0
Hydro power	4	7	0	0	0
Oil	4	4	13	7	1
Pumped-storage	11	2	0	0	1
Solar energy	27	39	3	6	10
Other (non-renewable)	0	0	0	0	4
Coal	24	3	31	37	28
Wind energy	3	3	0	10	8

Table 4.3 shows that waste is a minor fuel in all case states. In Hamburg, the installed capacity of waste-to-energy plants is the greatest but still only 5 %. Gas is the most important energy source in Berlin and plays an important role also in other states expect of Baden-Württemberg. Solar energy is the main energy source both in Baden-Württemberg and Bavaria that are the southernmost states in Germany. Combined capacity of coal and brown coal is 20-58 % in all other states except of Bavaria, where coal accounts only for 3 %. Biomass has a share of less than 10 % in all states ranging from 1% in Berlin to 8 % in

Hamburg. In Baden-Württemberg and Bavaria nuclear energy has a great share in installed capacity, which indicates major changes in energy supply since all nuclear energy plants will be closed by 2022.

4.4 Energy consumption

Electricity consumption of Finnish towns by year is published by the Finnish Energy Industries, an industrial policy and labour market policy association. Electricity consumption is presented divided into three categories: housing and agriculture, industry and service and building (Table 4.4).

Table 4.4: *Sectoral distribution of electricity consumption of the Finnish case cities in 2012 (Energiateollisuus 2013a)*

Municipality	Housing and agriculture (GWh)	Industry (GWh)	Service and building (GWh)
Espoo	961	132	928
Joensuu	285	699	242
Tampere	665	344	783
Turku	582	254	723
Vaasa	216	150	218

To compare the cities by specific consumption of energy, electricity and district heating consumptions are divided by number of inhabitants (Table 4.5).

Table 4.5: *Electricity and district heating consumption in Finnish case cities (Energiateollisuus 2013a,b)*

Municipality	Electricity consumption (GWh)	District heating consumption	Population 31.12.2013	Electricity consumption per capita (MWh/person)	District heating consumption per capita (MWh/cap)
Espoo	2021.0	2108.8	260842.0	7.7	8.1
Joensuu	1225.0	548.6	74477.0	16.4	7.4
Tampere	1791.0	2072.7	220579.0	8.1	9.4
Turku	1560.0	1748.3	182255.0	8.6	9.6
Vaasa	585.0	664.6	66357.0	8.8	10.0

Table 4.5 shows that the total electricity consumption is approximately proportional to population, only Joensuu has clearly higher consumption than it could be judged from the population number. In Joensuu, the consumption of industry sector is significantly higher

than that of any other case cities, which explains the difference. The weighted average of electricity consumption is 8.93 MWh/person. District heating consumption per capita is the greatest in Vaasa and the smallest in Joensuu.

Energy consumption data from German cities is taken from various sources, hence the values may not be accurately comparable and energy consumption data from Wuppertal was not available (Tables 4.6 and 4.7) The figures of Munich are from 2008, other consumption figures are from 2010 and population numbers are from 2011.

Table 4.6: *Sectoral energy consumption, primary energy consumption and final energy consumption of the German case cities (Statistik Berlin Brandenburg 2013, Statistisches Amt fü Hamburg und Schleswig-Holstein 2012, Kenkmann et al. 2012, Barthel 2009)*

	Berlin	Freiburg im Breisgau	Hamburg	Munich	Wuppertal
Households (GWh)	51398	4655	26480	12000	
Industry (GWh)	4715	1189	10374	118000	
Traffic (GWh)	18270	1186	16342	5300	
Primary energy consumption (GWh)	85103		69742	40400	
Final energy consumption (GWh)	74400	5200	53200	29000	
Population number	3501872	229144	1798836	1378176	349470
Final energy consumption per capita (MWh/cap)	21	23	30	21	0

Table 4.7: *Electricity and heat consumption per capita in German case cities (Statistik Berlin Brandenburg 2013, Statistisches Amt fü Hamburg und Schleswig-Holstein 2012, Kenkmann et al. 2012, Barthel 2009)*

Municipality	Electricity consumption (GWh)	District heating consumption (GWh)	Electricity consumption per capita (MWh/cap)	District heating consumption per capita (MWh/cap)
Berlin	12171,6	12921,3	3,5	3,7
Freiburg im Breisgau	1154,0	1069,0	5,0	4,7
Hamburg	11149,4	1696,7	6,2	0,9
Munich	7100,0	9500,0	5,2	6,9
Wuppertal				

According to tables 4.6 and 4.7, Berlin has the lowest electricity consumption per capita and Hamburg has the highest. Instead in district heating consumption, the highest consumption is in Munich and the lowest in Hamburg. Accurate listings of total heat energy consumption are rarely available. However, district heating consumption is not very informative in relation to energy efficiency, since coverage of district heating network is not similar in all cities. Length of district heating network affects also electricity consumption because alternative heating methods are usually electricity consuming.

Electricity and district heating consumptions of the cities are compared with population densities, which was said to affect greatly energy consumption of cities (Table 4.8).

Table 4.8: *Electricity and district heating consumption per capita in relation to population densities of the case cities.*

	Population density (1/km²)	Electricity consumption per capita (kWh/cap)	District heating consumption per capita (kWh/cap)
Espoo	809,1	7748,0	8084,6
Joensuu	31,0	16448,0	7366,0
Tampere	409,8	8119,5	9396,6
Turku	726,1	8559,4	9592,6
Vaasa	179,0	8816,0	10015,5
Berlin	3927,0	3475,8	3689,8
Freiburg im Breisgau	1497,1	5036,1	4665,2
Hamburg	2381,6	6198,1	943,2
Munich	4435,7	5151,7	6893,2
Wuppertal	2075,4	0,0	0,0

For example Tampere and Freiburg im Breisgau have relatively equal population numbers and both are inland cities, 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.

5 Strategies of the case cities

All the case cities have published strategies regarding climate 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 a lot 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 a strategy for the whole province instead of just the city itself. Some of the case cities have strategies both for the city itself and for a larger region.

Many of the below described strategies are based on various scenarios. By noticing the used scenario type it is easier to make suitable interpretations and conclusions. Börjeson et al. classify scenarios into six categories in an article Scenario types and techniques: Towards a user's guide. Forecasts and what-if scenarios are predictive scenarios and answer the question "What will happen?" Instead, predictive scenarios can be used for answering the question "What can happen?" Predictive scenarios include two sub-categories: strategic and external scenarios. Preserving and transforming scenarios form the third category called normative scenarios. Normative scenarios are created for answering the question "How can a specific target be reached?" (Börjeson et al. 2006) Especially normative scenarios are useful for drawing up strategies for cities to reach higher level targets. On the other hand, predictive and preserving scenarios help to foresee the possible development paths and to set realistic and reachable targets. Target scenarios for the development of the cities' energy systems are normative scenarios, business-as-usual scenarios predictive scenarios and scenarios of alternative development paths explorative scenarios.

5.1 Strategies on energy production

5.1.1 Espoo

In 2012, the city of Espoo had a municipal 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 5.1). Espoo aims for a reduction of greenhouse gas emissions by 39% 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. In objects 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 in all objects 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 one 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)

Table 5.1: *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
Bio fuels, heating plants, replacement of gas	257		286
Individual biomass heating solutions	629		786
Ground heat	629	-180	450
Heat recovery from waste water	350	-120	120-300
Solar energy	150	415-620	
Wind power		100	

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 bio fuels, 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 working group that drew up the strategy consisted of representatives from the municipalities of Helsinki, Espoo, Vantaa and Kauniainen and other stakeholders and interest groups. The core target of the strategy is to cut greenhouse gas emissions in the region by 39% compared to the level of 1990 by 2030. (Anderson et al. 2007)

Major plans regarding energy systems include efficient utilization of combined heat and power 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 of 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 various renewable energy sources, for instance 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% greenhouse gas 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)

5.1.2 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 objects for introduction of renewable energy solutions is not yet made. 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 the separate collection of energetic waste will be promoted and the volumes of energetic waste are expected to grow. (City of Joensuu 2014)

In the climate program, it is stated that 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)

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 very beneficial, since the biomaterial resources of the region are generous. Therefore the use of biogas will be promoted as soon as it is techno-economically reasonable. The share of biogas and electrical vehicles is aimed to be 10% of the total car pool in 2020. (City of Joensuu 2014)

The climate plan of Joensuu contains targets for promoting environmental-friendly means of transport, but more accurate plans are described in North Karelia's transportation plan from the year 2010. However, there are no exact percentual targets for the share of public or bicycle and pedestrian traffic. One of the key elements of the strategy is the improvement of competitiveness of passenger rail traffic by fastening the connections, matching timetables and starting to operate also at nights. (City of Joensuu 2014)

5.1.3 Tampere

The new climate and energy strategy of Pirkanmaa that is in the making in 2014 contains estimates on the distribution of energy sources in total energy mix (Table 5.2). The figure is based on the target of having 50 % renewable energy in the final energy production mix in 2040. (Pirkanmaan liitto 2013)

Table 5.2: *Mix of energy sources in final energy consumption in Pirkanmaa in 2011 and a target-based estimate for 2040. (Pirkanmaan liitto 2013)*

	Produced energy (GWh)			
	2011	Vision 2040	Change	Change (%)
Gas	6006	3500	-2506,00	-41,72
Oil	5728	1900	-3828,00	-66,83
Coal	57	0	-57,00	-100,00
Peat	1281	550	-731,00	-57,06
Imports	3362	1600	-1762,00	-52,41
Recycled fuels	0	800	800,00	
Wood and other biomass	3175	4600	1425,00	44,88
Hydro	487	550	63,00	12,94
Wind	1	500	499,00	49900,00
Solar	0	400	400,00	
Other (Ground heat and hydrogen)	237	600	363,00	153,16
Total	20334	15000	-5334,00	-26,23

Table 5.2 shows that significant 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 2013)

Recycled fuels include waste, sludge and industrial by-products. The new waste incineration plant will remarkably 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 2013)

5.1.4 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 transportation 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, p.8)

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 bio heating plant also 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 200 %. Targets related to waste management include collection and utilization of landfill gas in old landfill sites. In the target scenario, 40 % of energy is produced from renewable sources and total energy production, especially power production, will be slightly decreased (Table 5.3). (Vieno 2011)

Table 5.3: *Renewable energy production mix in region Southwest Finland in target scenario in 2020 (Vieno 2011)*

	Energy production in 2020 (GWh)
Wind	600
Woodchips	2000
Other wood fuels	1200
Other bioenergy (biogas, bio waste, 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 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, possibly a new regional waste incineration plant, wind power of Suomen Hyötytuuli Oy and nuclear power plant project of Fennovoima. 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 a self-sufficiency rate of 50% in environmental friendly energy production. (Turku Energia 2012)

The city of Turku started a project on biogas usage in public transport and other municipal traffic in 2010. The first phase of the project proved that the region has great potential for biogas production and for intensification of the usage of biogas. Therefore the second project was started in 2012 with the aim of making a more detailed report on the possible introduction of biogas as a transport fuel in 2014. An important part of the report was to clarify the possibilities of biogas utilization in public transport. (The City of Turku 2013)

In the final report of the project, it is stated that the current biogas production in Turku is 3 million m^3 per year and the volume could be relatively easily tripled in 10 years. Today, the biggest share of the biogas is produced from sewage sludge. The growth potential lies primarily in utilization of biowaste and other biomass in the existing plant. The biogas is typically supplied via natural gas network, but since Turku is not along the natural gas network of Finland, the distribution should be done with gas delivery cars, if new gas network is not economic to construct. It was estimated, that the most suitable solution for Turku would be fast fuelling stations in bus depots and other delivery points. The backup system for fuel supply would be LNG. (The City of Turku 2013)

After the report was published, the city council of Turku decided not to adopt biogas as a fuel for public transport, but to develop the system by broadening the use of electrical and hybrid vehicle technology. However, local biogas production will be promoted by offering for example parking benefits for biogas vehicles and directing more domestic and industrial biowaste for local biogas production. (The City Council of Turku 2013)

5.1.5 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. According to a report by Ramboll Oy, 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 in the region. 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, Pohjanmaa 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.

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 upcoming years and decades, alternative solutions 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 is aimed to lead to establishment of a biodiesel plant in Ostrobothnia. In addition, smart grids will be developed and demonstrated. (Wasberg et al. 2012)

5.1.6 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 in Berlin are photovoltaic, wind power and biomass. The produced amount of energy from each of the sources in 2005 and total production in 2020 according to target and reference scenarios are presented in figure 5.1. (Suck et al. 2011)

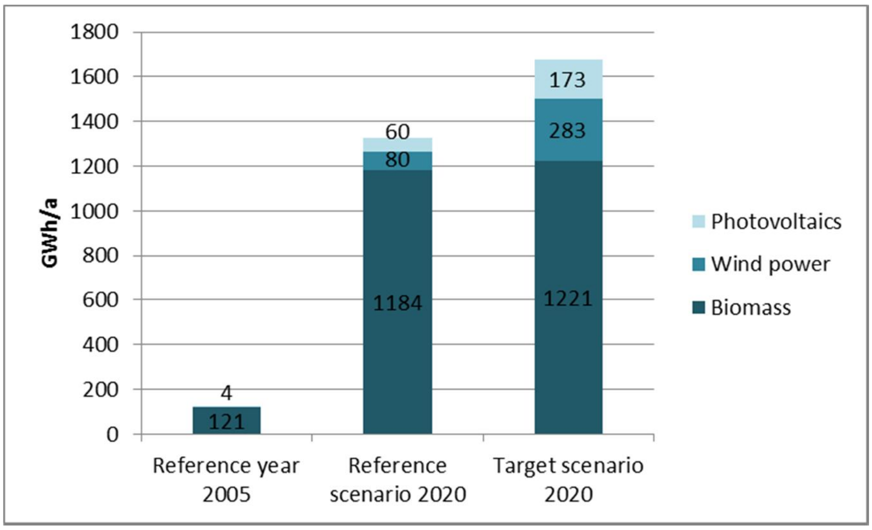

Figure 5.1: *Energy production from renewable sources in Berlin in 2005 and in 2020 according to different scenarios (Suck et al. 2011)*

The planned increase in biomass production is 1063 GWh/a in the reference scenario and 1100 GWh/a in the target scenario. Two biomass power plants are planned to be constructed by Vattenfall 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 capacity of 300 MW_{el} 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)

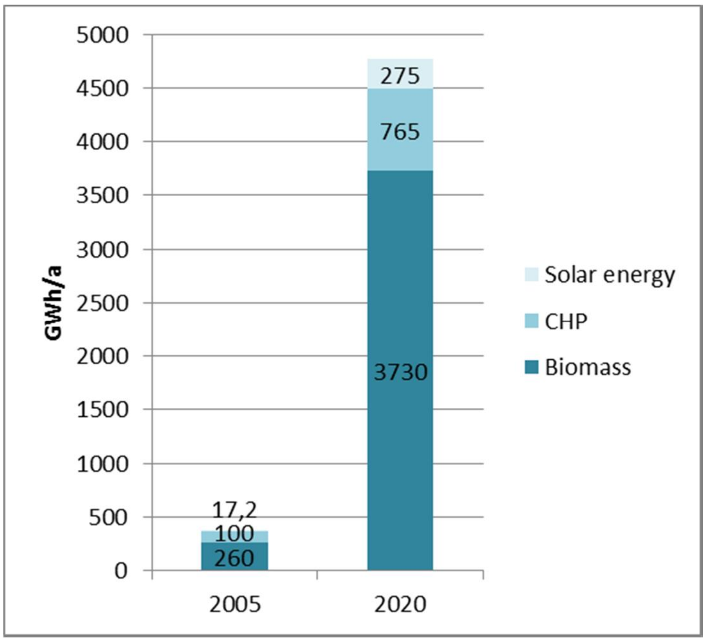

Figure 5.2: *Heat production from renewable energy sources in Berlin in 2005 and in 2020 (Suck et al. 2011)*

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 are 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 scenario, 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 the reference scenario for 2020, 10% of all heating systems in detached houses are biomass-based, 5% solar thermal devices and 10 % geothermal solutions. In multiple dwellings, the percentual shares of biomass, solar thermal and geothermal systems are expected to be 2.5%, 5% and 5%, respectively. In other buildings than dwellings, the share of renewable heating solutions is assumed to be 40%. 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 %. Heat production of individual heating systems, especially biomass-based-systems, is planned to increase significantly (Table 5.4). (Suck et al. 2011)

Table 5.4: *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	1347.4
Biomass	9	647	638	7088.9
Heat pumps	49	730	681	1389.8
Total	77	1652	1575	2045.5

In 2008 there were approximately 260 decentralized CHP units with maximum electrical capacity of 2 MW in Berlin and total electrical capacity of 15 MW. In the Energy concept 2020 the growth potential for decentralized CHP units is analyzed. According to the Energy concept, the biggest potential lies in private households (Table 5.5).

Table 5.5*: Growth potential of decentralized CHP production in Berlin until 2020 (Suck et al. 2011)*

	Amount of devices in 2020	Installed capacity in 2020 (MW)
Private households	1930	51.8
Municipal services	150	9.6
Business and trade	95	2.3
Total	2175	63.7

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 5.6). 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 5.6: *Energy consumption of the traffic sector in Berlin in 2005 and in two scenarios for 2020 (Suck et al. 2011)*

	Reference year 2005	Reference scenario 2020	Target scenario 2020
Shipping (GWh)	126	139	145
Air traffic (GWh)	3321	4815	4815
Road traffic (GWh)	14141	12020	11313
Rail traffic(GWh)	840	798	882
Total (GWh)	18428	17772	17155

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 expected to have only a negligible 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)

5.1.7 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 directs also the development of the energy system. In the climate protection strategy of Freiburg from 2007, four alternative scenarios of development 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. The 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 in both reference scenario and “Focus City” for 2020 and 2030 (Table 5.7). 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 reference scenario but with additional promotion measures in “Focus city”, the growth can be 21.0%. (Timpe et al. 2007)

Table 5.7: *Power production from renewable energy sources in Freiburg im Breisgau in reference scenario and in 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 (%)
Hydro power	1,9	2,8	2,8	47,4	2,8	2,8	47,4
Wind power	13,8	13,8	13,8	0,0	13,8	13,8	0,0
Photovoltaic	6	12	18	200,0	14	18	200,0
Landfill gas	10,2	0,8	0	-100,0	0	0	-100,0
Bioenergy	6,4	55,4	103	1509,4	7,8	7,8	21,9
Sum	38,3	84,8	137,6	259,3	38,4	42,4	10,7
Share of electricit	3,70 %	8,30 %	14,60 %		3,70 %	3,90 %	

The action plan contains for instance plans of 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 reducing CO_2 emissions by at least 90% by 2050. It is not an official strategy of the city, but the Institute for Applied Ecology and Energy Agency of the region Freiburg has drawn up the document commissioned by the city. 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 scenario (Tables 5.8 and 5.9). The fastest growing power production technology seems to be wind power in both 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)

Table 5.8: *Power production from renewable energy sources in Freiburg im Breisgau in target scenario (Kenkmann et al. 2011)*

Renewable energy source	2010 [GWh/a]	2020 [GWh/a]	2030 [GWh/a]	Change 2010-2030 [%]
Hydro power	2,3	2,5	2,5	8,7
Wind power	10	42	69	590,0
Photovoltaics	13,8	28,1	53,1	284,8
CHP	556	528,3	472,9	-14,9
Total	582,1	600,9	597,5	2,6

Table 5.9: *Power production from renewable energy sources in Freiburg im Breisgau in reference scenario (Kenkmann et al. 2011)*

Renewable energy source	2010 [GWh/a]	2020 [GWh/a]	2030 [GWh/a]	Change 2010-2030 [%]
Hydro power	2,3	2,5	2,5	8,7
Wind power	10	27	39	290,0
Photovoltaics	13,8	24,6	44,6	223,2
CHP	556	539,6	506,9	-8,8
Total	582,1	593,7	593	1,9

The energy strategy contains estimates on fuel consumption for power and heat production in the city area (Tables 5.10 and 5.11). In both 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 whereas in reference scenario the increase is only 65.6GWh/a. (Kenkmann et al. 2011)

Table 5.10: *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 [%]
Coal	64,8	0	0	-100,0
Natural gas	1729,7	1508,1	1005,4	-41,9
Heating oil	2	1,7	1,1	-45,0
Deponie gas	2	1,3	0,9	-55,0
Solid biomass	44	189,6	468,8	965,5
Biogas	27,3	57,1	71,4	161,5
Natural biogas	13,1	31,4	54,3	314,5
Biodiesel	0,2	0	0	-100,0

Table 5.11: *Reference scenario of fuel consumption in power and heat production in 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 [%]
Coal	64,8	0	0	-100,0
Natural gas	1729,7	1694,6	1564,9	-9,5
Heating oil	2	1,7	1,1	-45,0
Deponie gas	2	1,3	0,9	-55,0
Solid biomass	44	50	50	13,6
Biogas	27,3	54,3	62,9	130,4
Natural biogas	13,1	25,7	37,1	183,2
Biodiesel	0,2	0	0	-100,0

Heat production is planned to occur increasingly by centralized production. The usage of bio fuels depends highly on the availability and price of solid and gaseous biomass. In the target scenario, solid biomass will grow remarkably 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. The primary energy demand for centralized CHP production is estimated to be 1230 GWh in 2050 which would stand for 640 GWh of heat and 360 GWh of electricity. (Kenkmann et al. 2011)

The report Klimaneutrale Kommune 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. In a study “Untersuchung zu Kooperationsmöglichkeiten in der Freiburger Fernwärmewirtschaft” from 2004 it is evaluated, that the existing district heating network of Badenova can be further operated and even extended. District heating production and distribution should be optimized and connection density increased. Parallel district heating and steam network could be connected to gain synergy advantage. (Kenkmann et al. 2011)

In the report, potential for utilization of various renewable energy sources is estimated. The estimations are based on two reports by Öko-Institute: „Abschätzung des künftigen Anteils des Stromerzeugung aus Erneuerbarem Energien in Freiburg“ from 2011 that has not been published and „Klimaschutzkonzept für die Stadt Freiburg“ from 1995. 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 is 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%. In the short report of Öko-Institute the annual electricity production by photovoltaic in Freiburg would be 35 GWh/a in 2030. (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 of Freiburg is already fully exploited but the short report from 2011 estimates that hydro power production could increase 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)

The city of Freiburg im Breisgau has also published a traffic development plan in 2008. The traffic development plan contains similar measures and targets as the energy strategy: promotion of bicycle and pedestrian traffic as well as public transport to maintain the amount of car trips at a moderate level despite increasing mobility of people. An important part of the traffic plan is the concept “Stadt der kurzen Wege” (City of short distances) which means that the city will be developed also in the future in a way that minimizes the need for travel long distances to reach services and working places. (Huber-Erler et al. 2008)

5.1.8 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. Other important records are agreements with local energy companies, Environment Program for 2012-2015 and Climate Action Plan for 2007-2012.

In the climate protection plan, a vision for 2050 is presented to reduce CO_2 emissions by 80%. 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 Senate of Hamburg has set itself a target of being a leading state for energy-efficient housing and land-use. The plan is to start the construction of 6000 new dwellings annually. According to an agreement between the housing industry, districts and the Senate of Hamburg, the member companies are pursuing to reduce the average energy consumption of housing excluding hot water to an annual 133 kWh per square meter by 2020. Improvement of energy efficiency in existing buildings is supported by a funding program “Thermal insulation in existing buildings”. In 2010 approximately 10000 dwelling units received funding from the program. The volume of the funding program is planned to be remarkably increased in order to accelerate the building modernization rate. Additionally there is a separate funding program for non-residential buildings. (City of Hamburg 2011)

The agreement of co-operation between the city of Hamburg and Vattenfall AG contains measures for heat supply, modernization of 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. One 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 constructing more heating network and new connections along the existing network. By 2025, the amount of households connected to heating network should be increased by 20 % to 74 000. E.On Hanse Group plans to construct approximately 180 CHP plants with electric capacity of 5 kW – 2 MW in the city region. The total electrical capacity of CHP production shall 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 implementation of 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 municipal energy company Hamburg Energy has started a project called Smart Power Hamburg together with Hamburg University of Applied Sciences and RWTH. The aim of the project is to create solutions for connection of individual energy production units, especially small renewable energy applications, consumers and energy storages. The project is funded by the Federal Ministry of Economics and Technology as a part of the “EnEff:Wärme” program for energy efficient heating and cooling networks. (Smart Power Hamburg 2014)

The project is divided into seven subprojects. The first subproject aims for developing models of all individual units and interconnections to enable accurate simulation of the function of the system in various situations. One part of the project is optimization of the operation of CHP plants. Unlike wind and solar power plants, CHP plants are capable of adjusting their power with demand and therefore they are a key factor for balancing the smart energy system. To allow the control of CHP plants according to electricity demand, there must be effective techniques for storing the heat generated in the same process with electricity. In the project Smart Power Hamburg, there are three types of heat storages under consideration: heat networks, swimming pools and bunkers. These potential storages are systematically analyzed and possibly integrated to interconnected operation with the CHP plants. The integration and control of production units is to be done via a platform. New business concepts are developed for the operation and administration of virtual power plants. Free competition in the energy market and the integration of distributed production units should be promoted. It must be secured, that the operation of the plants is still reliable and that the security of supply is not endangered. (Smart Power Hamburg 2014)

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. Carbon dioxide 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, HamburgEnergy, 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)

In the transport sector, Hamburg highlights the potential of bicycle and pedestrian traffic. In the 2010’s, nearly 50 % of all car trips in the city are shorter than 5 km. The Senate of Hamburg has established a Cycling Action plan to set targets and to make plans for the expansion and development of the cycling network. The goal is to double the share of cycling in traffic from the 9% in 2002 by 2015. Public transport is to be improved by modernization and optimization of the bus system and construction of new underground and tram lines. The power supply for the tram and underground systems are also planned to be produced from renewable energy sources. (City of Hamburg 2011)

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)

5.1.9 Munich

The part “Climate change and protection” of the “Guideline Ecology” sets as a target 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 improving 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 only 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 500000 solar collectors and 80000 heat pumps in Bavarian buildings. The amounts are expected to be doubled annually in the upcoming years. In 2021 the share of energy production of 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 the total final energy consumption and 10 % of the electricity consumption. Potential biofuels include biomass, biowaste, wood fuels and straw. More efficient conversion processes are being developed, gasification of biomass among others. (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)

In 2013, 70% of the electricity in the region of Munich was produced in CHP plants. During the upcoming 10 years, new district heating connections with total capacity of 700 MW are expected to be built. (Müller et al. 2013, p. 25, 27)

Stadtwerke München is the local energy company owned by the city. In 2008 SWM launched a Renewable Energies expansion campaign that aims for increasing renewable energy production to approximately 7.5 billion kilowatt hours, an amount equivalent to the energy consumption of the city of Munich. SWM 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)

At present, SWM operates 19 photovoltaic units in Munich. The roofs of many public buildings are covered with photovoltaic panels. For example, the Munich Technology Center, constructed in 2008, has an area of 497 m² covered with photovoltaic modules with total capacity of 66.85 kWp. The annual power production is approximately 64000 kWh. The photovoltaic system is combined with a green roof, which helps to decrease the surface temperature of the roof and therefore improve the efficiency rate of the panels. Furthermore, various companies and private households have their own solar energy systems. (Stadtwerke München 2013)

The current wind energy capacity of SWM is 2.3 MW. SWM is participating in several wind power projects in 12 European countries. There are plans for several thousands of megawatts of new wind power capacity in the upcoming years and many projects are already in the works. In Bavaria, there are plans for producing approximately one billion kilowatt hours by 2020. SWM has also carried out projects related to additional hydropower. By modernizing existing hydro power plants, SWM plans to produce annually 6.3 million kWh more hydropower than before in the upcoming years. (Stadtwerke München 2013)

SWM is constructing a geothermal cogeneration plant that has a capacity of 5 MW of electricity and 4 MW of heat. SWM utilizes geothermal energy already in a 9 MW geothermal heating plant opened in 2004. Third geothermal plant is under consideration in the new suburb of Freihamm. The plant would be integrated to an existing heating plant. The production units of SWM are operated centralized as a virtual power plant. (Stadtwerke München 2013)

In addition to the projects in Munich and the region, SWM is participating in several projects in other locations with the aim of producing the same amount of renewable energy as the total energy consumption of the whole city. For example, SWM owns shares of several onshore wind power parks in various states in Germany and other European countries, offshore wind power parks in the North Sea and Irish Sea and a share of a 50 MW large-scale solar power plant in Spain. (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, replace 5 % with bicycle and pedestrian traffic and 10 % with public transportation. 10% of private car kilometers should be driven with electrical vehicles that use green energy and 3% biogas vehicles. Railway traffic should be solely powered by green energy and the fuel that buses use should be 100% biogas. (Karg et al. 2013)

5.1.10 Wuppertal

In the climate plan of Wuppertal, it is laid 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. 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 composed heat could be used. In 2007, total power production of CHP plants was 240 GWh and production of condensing power plants was 507 GWh. 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)

Chapter six of the final report of the document “Low Carbon City Wuppertal 2050” handles space heating. The total final energy consumption in space heating in 2010 was about 2510 GWh. Gas and oil were the most common energy sources, district heating accounted for 9.8% of the total final energy consumption and heating methods based on renewable energy sources had only minor shares. In two different target scenarios for 2020, additional growth of utilization of renewable energy in space heating is planned to be implemented mainly by increasing solar energy production. 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 (Table 5.12). (Reutter et al. 2012) Scenarios are drawn up for 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 (%)	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/cap)	7,2	7,01	6,85	6,09

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 manner, three goals are in a central role. The need for traffic should be reduced and technologies improved towards better energy efficiency and to replace motorized private transport 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 final report of the project, potential for bioenergy in the region is analyzed. The results of the analyze of energy wood potential reveals that 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% old wood, 22% sawing waste and 14% from landscape conservation.(Valentin 2011)

The federal state Nordrhein-Westphalien has a biomass action plan "Bioenergie.2020.NRW" where concrete measures for utilization of biomass are defined. It is estimated in the biomass action plan that the unused biomass potential of the region is about 21 TWh/a. By 2020, the bioenergy production should be increased from 10.6 TWh in 2007 to 17.8 TWh supplying electricity to 20% of all households in Nordrhein-Westphalien and heat to 9% of all households. Agriculture should provide 53% of the potential resources which means that 17% of the field areas should be utilized for cultivation of energy plants. (Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen 2009)

Table 5.14 shows that energy plants, forest wood and straw are estimated to have the biggest potential in addition to improved energy efficiency in Nordrhein-Westphalien. Biofuels are not considered in the action plan due to the fact the only a minor part of the raw stock comes from the region itself. (Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen 2009)

Table 5.14: *Distribution of exploitable biomass potential in Nordrhein-Westphalien (Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen 2009)*

Resource	Pergentage (%)
Energy plants	27
Straw	13
Intermediate plants	4
Manure	5
Short transition plantations	5
Forest wood	19
Landscape conservation	2
Sawing waste	10
Bio waste	2
Improved efficiency	13

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)

5.1.11 Summary of future plans for energy systems

Different level targets define guidelines for the development of urban energy systems. There are international targets, official national strategies and programs of the city councils. In addition, there are various movements and alliances that aim to support and promote the development of urban systems. Membership of these groups is usually voluntary, but many of the case cities have decided to join them. The level of power of decision in energy issues in cities varies. In Tampere, Turku, Vaasa, Munich and Wuppertal, the local 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.

Those cities that set numerical targets for renewable energy production have in general higher targets than the national level (Table 5.15). Some of the cities have defined the targets in a different way. For example 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. The values for Freiburg are summarized from the target scenario of the document "Freiburg 2050 –Auf dem Weg zur Klimaneutralität" and therefore they are not official targets of the city. Espoo, Hamburg and Wuppertal have not published numerical targets for renewable energy production in the future and hence their rows are left blank.

Table 5.15 *Targets of the case cities for production and consumption of renewable energy*

City	Targets on renewable in energy production	Source
Espoo		
Joensuu	In 2025: 90% of the total energy consumption covered with renewable energy production	Climate Program of the city of Joensuu from 2013
Tampere	In 2040, 50% renewable energy in final energy consumption	Bulletin of a draft of new Climate and Energy strategy for Pirkanmaa from 2013
Turku	In 2020, 40% of energy production based on renewable sources. Sectoral targets: 50% in heating and cooling, 33% in electricity, 20% in transport	Energy strategy of the region Southwest Finland for 2010-2020 from 2012
Vaasa (Pohjanmaa)	In 2020:heating: 50%, electricity: 70% ja transport: 20% , in 2050 100% in all sectors (renewable fuels)	Energy strategy and action plan of region Pohjanmaa from 2012
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	Energy concept 2020 for Berlin from 2011
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	A report Freiburg 2050 - Auf dem Weg zur Klimaneutralität from 2011
Hamburg		
Munich	In 2025, total power production of the municipal energy company equivalent to the total electricity demand of the city,	SWM Ausbauoffensive Erneuerbade Energien from 2014
Wuppertal		

The renewable energy targets are in most cases derived from greenhouse gas reduction targets. Specific greenhouse gas reduction targets are set first and suggested measures for reaching the targets include increasing renewable energy production. An official or upper-level greenhouse gas reduction target can be used as a starting point for producing a normative scenario about the development of the energy system.

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.

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. Promoted heating technologies are especially district heating, heat pumps, ground heat utilization and solar thermal devices. All the case cities state that they will continue using and extending the district heating networks in their area since combined heat and power production increases significantly the efficiency rate of centralized combustion plants. Other renewable heating solutions are supported mainly outside the district heating network. It must be noticed, that implementation of heat pumps, ground heat systems and solar thermal collectors raises electricity demand. In Germany, utilization of bioenergy is planned to be promoted in many cases by co-combustion of biomass in fossil fuel -fired plants. In the heating sector both individual bioenergy heating systems and district heating are planned to account for a bigger share of the cities' heat production during the upcoming years. Waste management is also mentioned in many of the strategies.

5.2 Energy consumption targets

Energy saving is an effective method for reducing carbon dioxide emissions 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 hard to predict, also the total demand for energy may vary.

5.2.1 Energy consumption targets of the case cities

Espoo

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

In the climate strategy, 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)

About land-use planning, it is stated that the capital area is resembles more North-American cities than other European cities because of sparse urban structure. Long distances increase annual traffic kilometers and as a result also 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)

Joensuu

In the climate strategy of Joensuu region, the energy efficiency 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 improving the energy efficiency of municipal buildings. Remarkable 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 2013)

Tampere

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. The focus of energy saving actions is in other sectors than industry. Key areas for energy saving measures are procurement, housing and construction, traffic and mobility, waste and recycling and education and consulting. Unnecessary purchases shall be avoided and decision criteria should be based on energy and material efficiency and sustainability. (Pirkanmaan liitto 2014)

It is planned according to the energy and climate strategy that old buildings will be energetic renovated in liaison with other reconstruction and new buildings will be constructed according to energy efficiency standards. Greenhouse gas emission reduction in transport sector will be realized through improved public transportation and dense urban structure. Composition of waste will be prevented, recycling promoted and the waste that still remains 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)

Turku

The energy strategy of Southwest Finland contains a vision for 2020 about energy consumption. According to the vision, total energy consumption would stay on the same level as in 2007 although energy demand of 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 2010, the production based primary energy consumption of Turku region was 12 400 GWh. The distribution of energy sources in production based energy consumption in 2010 shows that coal is the most important energy source with the share of more than 40 %. Bioenergy has a share of 9 % and other renewable energy sources only 2 % (Figure 5.3). (Kuusiola et al. 2012)

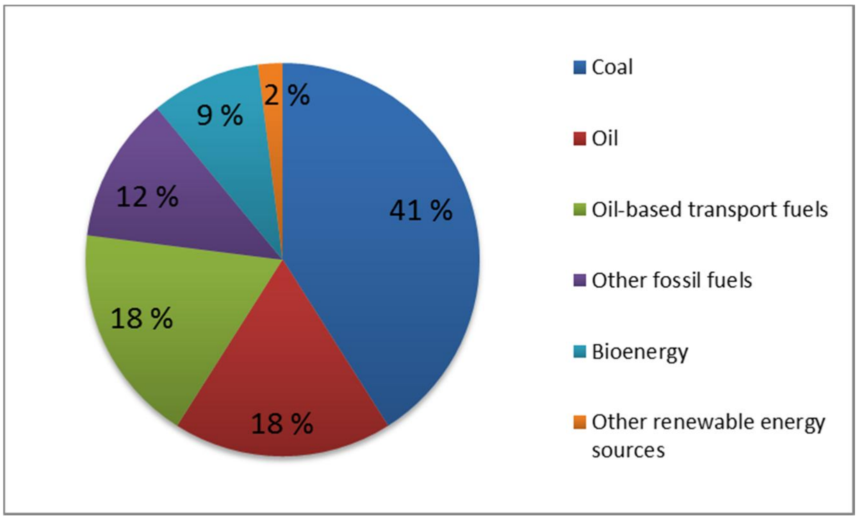

***Figure 5.3:** Distribution of energy sources in production based primary energy consumption in Turku region in 2010 (Kuusiola et al. 2012)*

In the reference scenario, 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 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 %. (Uitamo 2010)

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 should act as forerunners in energy efficient construction. (Uitamo 2010)

Vaasa

The energy strategy of the region Pohjanmaa contains assumptions about the development of energy consumption and production until 2020 (Table 5.16). 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. Greenhouse cultivation, which is an important trade for the region should cut energy consumption by area by 30 % and half of the farms should utilize renewable energy in 2020.. (Wasberg et al. 2012)

Table 5.16: *Consumption of different forms of energy in Pohjanmaa in 2008 and 2020 (Wasberg et al. 2012)*

	2008 (GWh/a)	2020 (TWh/a)	Change (GWh/a)
Heating (excluding electrical heating)	2500	3000	500
Greenhouse cultivation	700	500	-200
Electricity	3500	5500	2000
Transport	1500	1000	-500
Total	8200	10000	1800

Table 5.16 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 which is mostly caused by the industry sector. Instead, in transport sector and greenhouse cultivation energy consumption is decreasing. (Wasberg et al. 2012)

Berlin

The core target of the energy concept of Berlin is to cut carbon dioxide emission by 40% by 2020. To reach the desired reduction, 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. The most significant change is calculated for heating sector where energy consumption per year should decrease by more than 4000 GWh (Figure 5.4). (Suck et al. 2011)

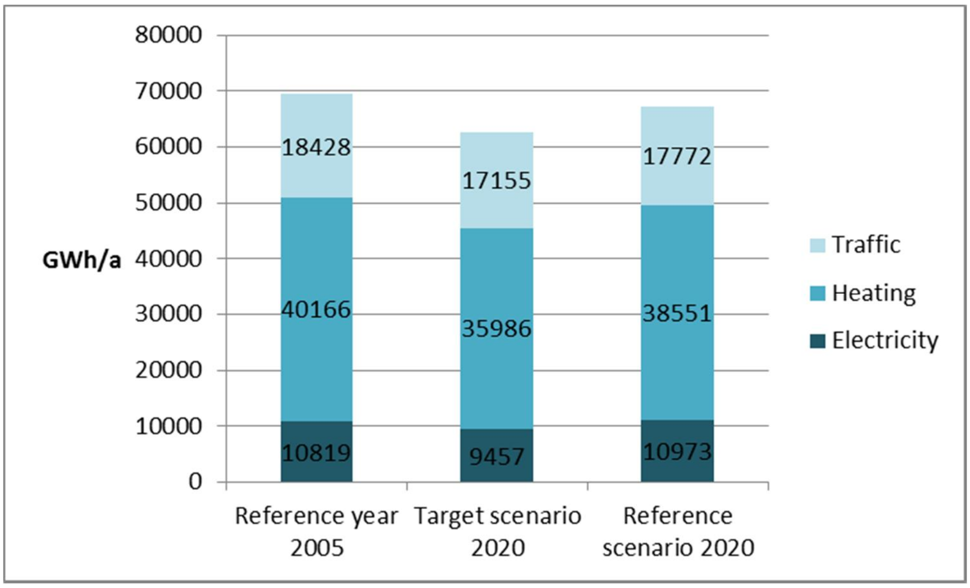

Figure 5.4: *Final energy consumption by sector in Berlin in 2005 and target scenario for 2020 (Suck et al. 2011)*

The energy saving targets are defined separately for the following sectors: private households, small industries, trade and services, industry and traffic (Figure 5.5) Private households are observed to have the highest demand for energy in 2005 whereas industry accounts only for a minor share of the total energy consumption of the city. The percentual distribution of energy consumption is estimated to remain approximately unchanged. (Suck et al. 2011)

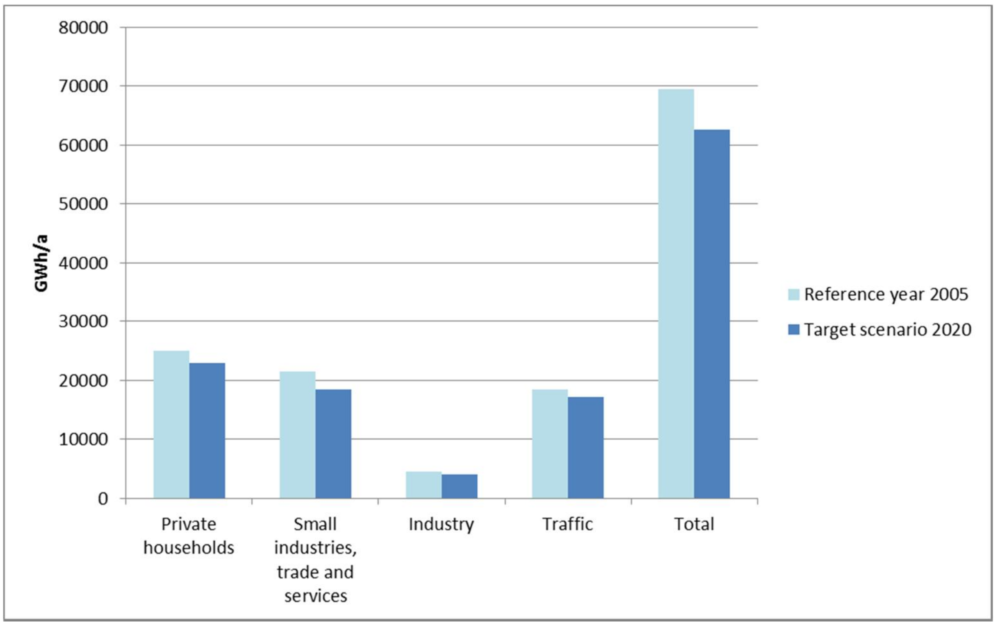

Figure 5.5: *Sectoral energy consumption in Berlin in 2005 and in 2020 (Suck et al. 2011)*

The annual reconstruction rate of buildings is assumed to remain at 0.7% in the upcoming years. The energy consumption of private households is estimated to decrease by approximately 3.6% without additional energy saving and energy efficiency measures. The demand for heat would decrease by about 4.6% from 21 604 GWh to 20 614 GWh and demand for electricity increase by 2.7 % from 3402 GWh to 3494 GWh compared to 2005. In the target scenario for 2020, the reconstruction rate of Berlin would have increased to 2%. Demand for heat in private households would decrease by 7.5% to 19 982 GWh and demand for electricity by 13.1% to 2957 GWh. In the reference year 2005, 13 174 GWh of electricity was consumed in Berlin. 70.2 % of the total amount was generated in Berlin and 38.1 % of the power production in Berlin was combined heat and power production. (Suck et al. 2011)

Hamburg

In the climate action plan of Hamburg, energy saving and improving energy efficiency are listed as two of the total 13 key goals of sustainable climate action. Energy saving actions are said to be focused on areas where most greenhouse gases are composed, that is in Hamburg's case industry and plant engineering, transport and buildings. Energy efficiency improvements are needed to ensure economic growth without increasing emissions. Highlighted actions include lowering emissions in building and housing by improving energy efficiency of both existing and new buildings and in transport sector by promoting public, pedestrian and bicycle traffic and by implementing innovative technologies such as electric vehicles. Energy and resource efficiency in industry sector is also promoted by funding and co-operation programmes. (City of Hamburg 2011)

Munich

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) In the climate protection concept, the saving potential of electricity consumption in 2010-2030 was assumed to be 18%, heat consumption 19% and fuel consumption 10%.(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. The current building stock consists of 750000 apartments and the annual construction rate of new apartments is approximately 6000. 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)

Freiburg im Breisgau

In 2010, the total final energy consumption in the city of Freiburg im Breisgau was 5200 GWh. Industry accounted for 1010 GWh which is about 19% of the total energy consumption and traffic sector accounted for about 23 % with 1190 GWh. (Statistisches Landesamt Baden-Württemberg 2013)

In the reference scenario of the climate protection strategy of Freiburg, the final energy consumption of the city would be decreased by 5% by 2020 and by 7% by 2030 compared to 2005. The share of natural gas is expected to increase from 25% to 28% by 2030 and the share of heat from renewable energy sources is expected to be doubled to about 3 % in 2030. Instead, in the scenario "Focus city" the final energy consumption is decreased by 14% by 2030. In demand for various fuels, the biggest difference 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, 2030, 2040 and 2050 is calculated based on both reference and target scenarios. Energy demand is defined separately for different forms of energy (Tables 5.17 and 5.18). (Timpe et al. 2007)

Table 5.17: *Energy demand by energy form in the reference scenario in 2010, 2020 and 2030 (Timpe et al. 2007)*

Energy form	2010 [GWh/a]	2020 [GWh/a]	2030 [GWh/a]	Change 2010-2020 [%]	Change 2020-2030 [%]
Electricity	1154	1090	1079	-5,5	-1,0
Natural gas	996	967	798	-2,9	-17,5
Heating oil	641	388	199	-39,5	-48,7
District heating	1069	1049	961	-1,9	-8,4
Ground heat	45	78	110	73,3	41,0
Solar heating	59	83	109	40,7	31,3
Biomass	94	123	152	30,9	23,6
Coal	34	20	11	-41,2	-45,0
Renewable cooling	0,3	0,9	2,6	200,0	188,9
Petrol	458	307	251	-33,0	-18,2
Diesel	648	681	629	5,1	-7,6
Liquid gas	4	9	12	125,0	33,3
Hydrogen/Fuel cells	0	0	1		

In the reference scenario, significant decreases in 2010-2030 are expected in demand for natural gas, heating oil, district heating, and petrol. Also demand for electricity will diminish. Growing energy forms include ground heat, solar heating and biomass, but the increases are less than 100 GWh/a until 2030. (Timpe et al. 2007)

Table 5.18: *Energy demand by energy form in the target scenario in 2010, 2020 and 2030 (Timpe et al. 2007)*

Energy form	2010 [GWh/a]	2020 [GWh/a]	2030 [GWh/a]	Change 2010-2020 [%]	Change 2020-2030 [%]
Electricity	1159	1008	866	-13,0	-14,1
Natural gas	1001	841	454	-16,0	-46,0
Heating oil	634	262	83	-58,7	-68,3
District heating	1053	854	788	-18,9	-7,7
Ground heat	49	114	132	132,7	15,8
Solar heating	63	131	141	107,9	7,6
Biomass	101	129	135	27,7	4,7
Coal	34	11	4	-67,6	-63,6
Renewable cooling	3	19	46	533,3	142,1
Petrol	458	271	184	-40,8	-32,1
Diesel	631	689	428	9,2	-37,9
Liquid gas	4	8	14	100,0	75,0
Hydrogen/Fuel cells	0	3	9		200,0

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)

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. Great potential for emission reduction lies also in domestic water heating. On the contrary, only moderate savings 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 the company Rhodia. Energy savings in industry sector can be reached by improving the processes. Despite the fact that expected growth of the industry sector, final energy consumption of the sector could be reduced by more than 30% by 2050 (in figure 5.6). (Timpe et al. 2007)

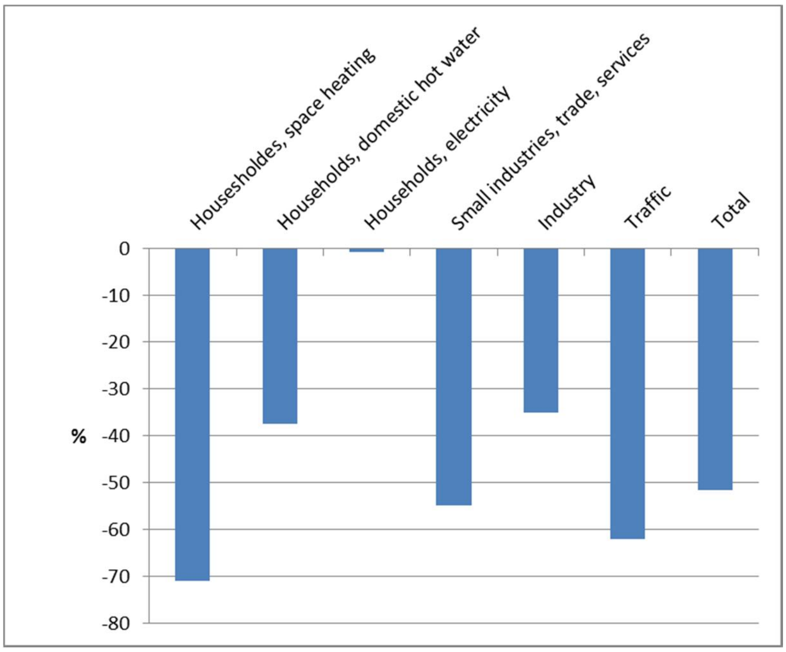

Figure 5.6: *Sectoral final energy saving potential compared to 2010 by 2050 (Timpe et al.2007)*

<u>Wuppertal</u>

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 action 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 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. (Wuppertal 2009)

In the study “Low-carbon city Wuppertal 2009”, it is stated 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 greenhouse gas emissions. (Reutter et al. 2012)

5.2.2 Summary of energy consumption targets

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 and various operations, by considering energy efficiency as one of the determining factors for buying decision 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.

As a conclusion, few cities have set accurate and comprehensive targets on the total energy consumption, probably mainly because cities can mainly control the energy use or municipal actions (Table 5.19).

Table 5.19: *Targets of the case cities related to energy consumption*

Municipality	Targets	
Espoo (capital area)	Electricity consumption stops increasing by 2030, specific heat consumption of the existing building stock decreases by 20% by 2020 , specific heat consumption of new buildings 45kWh/m² in 2020	All Finnish case cities have voluntarily pledged to reduce the energy consumption of municipal actions by 9% in 2005-2016
Joensuu	Total energy consumption -25% by 2025 compared to 2007	
Tampere	Energy consumption is planned to be cut by 1 % annually until 2040.	
Turku	Total energy consumption is estimated to remain on the current level until 2020 and then to start decreasing	
Vaasa (province of Pohjanmaa)	Expected increase in final energy consumption mainly caused by the industry sector	
Berlin	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	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	Energy saving listed as one of the key goals for climate protection, especially in areas with the consumption i.e industry and plant engineering, buildings and transport	
Munich	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	Individual projects on energy saving	

6 Classification of the case cities

Upper-level targets, such as EU policies and national strategies, build the framework for development of energy systems of cities. Therefore all studied cities in Finland and Germany have many similarities in targets, for example, improved energy efficiency, energy saving and promotion of renewable energy production. However, some city categories with typical characteristics can also be identified.

6.1 Ambitiousness of the case cities in energy issues

Some of the case cities are clearly aiming to become or remain forerunners in energy issues while others focus on reaching upper-level targets with more traditional solutions (Tables 6.1 and 6.2). Hamburg, for example, has several ongoing pioneer projects on energy storage, decentralized energy production, virtual power plants and electric vehicles. Freiburg Im Breisgau has a long tradition of being the green city of Germany, and the current targets of for example ending all coal combustion show that the city will keep its green image. Munich has also ambitious plans, since the municipal energy company aims at producing the same amount of renewable energy as the total city consumption, which is in line with the targets of the city itself. Berlin has published a comprehensive energy strategy, but the targets are on the same level as the national targets and hence it is not considered as a special forerunner. Wuppertal has announced only the targets of the Alliance as its official energy related targets, and since the planned measures include mainly measures that can be found in several other cities' strategies as well, Wuppertal is also considered as a less innovative case city.

Vaasa aims at being a leading center for zero-emission energy technologies in Finland and in the whole Europe together with the region Ostrobothnia. The region aims at gaining the reputation of being a clear forerunner in modern energy solutions. Joensuu can also be considered as a city with exceptionally high targets, since it aims at having 90 % of final energy consumption produced from renewable energy sources in 2025. A great share of energy consumption in Joensuu is already produced with biomass and hydro power and the city has published only quite rough plans for increasing renewable energy production. Therefore the role of Joensuu as a forerunner is rather difficult to evaluate, but since the targets are clearly higher than in any other case city, Joensuu is categorized as a forerunner. Turku's renewable energy targets are similar to those of Finland, and though the region Southwest Finland aims at becoming a carbon neutral province already by 2030, Turku is not classified as a particular forerunner among the case cities. Espoo's main target in the climate strategy is to reduce carbon dioxide emissions by 39% by 2030 compared to the level of 1990, but the city has not published any specific renewable energy targets or plans for large-scale projects and hence Espoo is not considered as a particular forerunner city either. Tampere and the region Pirkanmaa have longer-term targets for renewable energy production thus they are not perfectly comparable with national and other cities' targets. However, energy related actions of Tampere are not as ambitious and concrete as the ones of the particular forerunner cities. As a result, also Tampere is categorized outside the forerunner cities.

6.2 Scale of energy production and specific focus areas

One distinguishing factor is the scale of energy production (Tables 6.1 and 6.2). All the case cities have currently mainly centralized energy production systems, but decentralized production technologies have drawn attention lately due to developed technologies both in production and distribution. It must also be noticed that information on smaller-scale energy production units is not necessarily easily available, whereas bigger production units must be listed in official power plant databases.

6.2.1 Scale of energy production units

Hamburg has significant decentralized energy production in addition to centralized plants and an ongoing project for improving preconditions for more remarkable decentralized production. In Freiburg im Breisgau, there are two famous housing areas with a decentralized energy production systems. Although decentralized production accounts only for a minor share of the total energy production of the city, more than 6% of the population of the city lives in the areas, hence the decentralized systems are worth considering. In Berlin, fossil fuel –fired centralized CHP plants are planned to be converted into plants that cause less CO_2 emissions. For example, a 300 MW_{el} and 230 MW_{th} gas CHP plant is under planning. Co-combustion of biomass is also planned for several centralized coal –fired CHP plants. However, there are also plans for additional decentralized energy production, especially in the heating sector. Therefore it can be stated, that energy production will remain mainly centralized in Berlin, but especially distributed heat production and CHP production will be increased. Wuppertal plans to promote for example solar energy, wood pellet and wood chip boilers and decentralized CHP production. However, there are four big-scale CHP plants with total electrical capacity of 253 MW. Since there are no official plans for replacing the plants, the energy production system is assumed to remain mostly centralized. In Munich, both centralized and decentralized CHP production is promoted. Current small-scale production methods include solar energy, wind power and geothermal energy and the production units are already operated as a virtual power plant. Utilization of all technologies mentioned above is planned to be increased. However, there are also three large-scale CHP plants whose total electrical capacity is 1216 MW. As a conclusion, energy production in Munich is assumed to be mostly centralized but to a greater extent also decentralized in the future.

The energy system of Espoo is based on centralized energy production units. In the climate strategy of the capital area fossil fuel –based centralized energy production is planned to be converted to utilize technologies and fuels that cause less emission. Decentralized production will be increased especially by promoting decentralized heating solutions outside the district heating network. One of the coal-fired CHP plants in Turku is planned to be replaced by a new multi-fuel plant that can combust biomass, coal and recycled fuels. The capacity of the plant will be 142 MWe and 244 MWth, hence the plant strengthens centralized power and heat production in Turku area. However also potential for decentralized CHP production is announced to be investigated and individual heating solutions are promoted. In Joensuu, there are plans for replacing peat by biomass at the biggest CHP plant. As the second biggest energy production unit is an industrial CHP plant that can be assumed to continue production as long as the pulp mill is in operation, it can be concluded that energy production will remain mainly centralized in Joensuu. However, there are also some smaller production units and further plans for decentralized heat production. In the climate and energy strategy of Pirkanmaa, decentralized energy production is said to be promoted. On the other hand, new centralized production plants are under construction and the major plants can be assumed to continue operation for many years. As a result, energy production is stated to be both centralized and decentralized in the future. Also in Vaasa, current energy production capacity is mainly centralized. There are plans for especially additional wind production in the province and also decentralized heat production is announced to be promoted, hence energy production can be said to remain mainly centralized but also to a greater extent decentralized in Vaasa.

6.2.2 Specific focus areas in energy system development

Some of the case cities have a key technology that is planned to be promoted particularly strongly, whereas others aim at reaching emission or renewable energy targets without clear preferences in technologies.

Vaasa and the region Ostrobothnia aim at becoming a leading area for wind power production in Finland. Although most of the wind power capacity is likely to be installed outside the city borders of Vaasa, significant increases in wind power production in the area affect strongly the power supply and decision making also in Vaasa. In the climate strategy of Espoo and the capital region, especially promotion of CHP production and in connection also district heating and cooling are underlined. In the draft of the climate and energy strategy of Pirkanmaa, potential of various technologies and concepts are said to be investigated. Biomass and recycled fuels seem to have the biggest importance in the future of the mentioned technologies. In the climate strategy of Joensuu and the region, potential of alternative renewable energy technologies is not analyzed in detail hence targets concern mainly increases in renewable energy production in general. In the energy strategy of Turku and the Southwest Finland, especially utilization of wood chips is planned to be increased. Also many other renewable energy technologies are said to be promoted, especially wind power production and heat pumps.

In the strategies of Hamburg, energy storage technologies and smart systems have a stronger focus than in the strategies of other case cities. In Freiburg im Breisgau, plans for increasing utilization of photovoltaic are significant and the city has a reputation of being a pioneer in introduction of solar energy systems. Other important concepts for Freiburg are ecological and energy efficient neighbourhoods with decentralized energy systems. The city of Wuppertal and the municipal energy company Wuppertaler Stadtwerke have announced that they aim to increase energy efficiency and production of renewable energy but special focus areas are difficult to detect. Technologies that are mentioned to be promoted include solar energy, wood pellet and wood chip boilers, heat pumps, natural gas vehicles, small-scale CHP boilers and district heating. In the strategy of Berlin, production amounts of various technologies in different scenarios are estimated in detail. Many technologies that are planned to grow in importance are mentioned, but in all the scenarios the increase in the utilization of biomass is the greatest. In Munich, several technologies are promoted to reach the renewable energy production targets and special focus areas are difficult to detect.

Table 6.1. *Characteristics of the German case cities*

City	Forerunner/Follower	Centralized/Decentralized solutions	Special focus areas
Berlin	Follower	Mainly centralized, also distributed CHP production in use and further potential being investigated	Biggest increases in renewable energy production planned for bioenergy, also wind and solar energy ans small-scale CHP production
Freiburg	Forerunner	Mainly centralized, also areas with decentralized solutions	Solar energy, ecological and energy efficient neighbourhoods with decentralized energy systems
Hamburg	Forerunner	Mainly centralized, also decentralized production that will be further developed and supported	Smart systems, energy storage technologies, electric vehicles
Munich	Forerunner	Mainly centralized, decentralized production increasing and supported	Hydropower, solar energy, bioenergy, wind energy, district heating, smart systems, geothermal energy
Wuppertal	Follower	Mainly centralized, decentralized production increasing and supported	Solar energy, wood pellet and wood chip boilers, heat pumps, natural gas vehicles,, small-scale CHP boilers, district heating

Table 6.2 *Characteristics of the Finnish case cities*

City	Forerunner/Follower	Centralized/Decentralized solutions	Special focus areas
Espoo	Follower	Centralized, plans for decentralized production	CHP production, district heating and cooling, heat pumps, ground heat and solar energy devices, waste incineration, gas combustion
Joensuu	Forerunner	Both centralized and decentralized	Solar, wind and wood energy, replacement of oil boilers with pellet or wood chip boilers
Tampere	Follower	Mainly centralized, plans for decentralized production	Recycled fuels and biomass
Turku	Follower	Centralized, potential of small-scale CHP production being investigated	Wood chips, wind power, heat pumps
Vaasa	Forerunner	Mainly centralized	Wind power, heat pumps, ground heat, waste gasification, electric vehicles, alternative transport fuels (region Pohjanmaa)

6.3 Role of bioenergy in the case cities

When considering bioenergy, the case cities can be classified into cities where bioenergy plays a major role in future strategies and cities where bioenergy is planned to be mainly a supplementary energy source. In Joensuu, the biggest power plants are already bioenergy-based to a great extent and peat is planned to be replaced by biomass in the near future, hence bioenergy will be clearly the main energy source also in the future. Joensuu is the only case city where bioenergy is the main energy source. In other Finnish case cities Espoo, Tampere, Turku and Vaasa, bioenergy is planned to replace fossil fuels in existing centralized production units or already replacing, as in Tampere and Vaasa. In all the German case cities, bioenergy is a minor energy source. In Hamburg, Wuppertal, Munich and Berlin, there is some biogas production and in Wuppertal, Hamburg and Berlin, also biomass is used for energy production. Future plans contain mainly promotion of small-scale bioenergy production and replacement of fossil fuels by biofuels in existing centralized production plants.

Table 6.3: *Role of bioenergy and future plans with regard to bioenergy in the case cities*

City	Role of bioenergy	Specific plans
Berlin	Supporting energy source, plans for significant increses in biomass usage	Construction of new biomass-fired CHP plants, co-combustion of biomass. In the heating sector, biomass is planned to be the most important renewable energy source by 2020, both decentralized and centralized heating solutions
Freiburg	Small-scale bioenergy production, only a minor share of total production	Scale of bioenergy plans varies heavily between different scenarios. Possible plans: replacement of natural gas by biogas in centralized energy production, decentralized wood-based heating systems
Hamburg	Several biogas plants, supporting role in energy production	The city promotes especially decentralized (>100kW) bioenergy plans, local energy company considers co-combustion of biomass eith coal in an existing centralized CHP plant
Munich	Biogas production in the city, bioenergy already important in the whole state and plans for further utilization	In the state of Bavaria, increasing utilization planned for biomass, biowaste, wood fuels and straw, biogas as balancing power
Wuppertal	Supporting energy source: combined biogas and CHP production	Wood pellet and wood chip boilers promoted
Espoo	Supporting energy source	Partial replacement of coal and gas in power production
Joensuu	Main energy source	Replacement of old oil boilers by wood chip or pellet -fired boilers
Tampere	Supporting energy source, importance growing	Construction of a new wood fuel -fired heating plant. Biggest increases planned for additional usage of wood fuels: currently used fuels will be further utilized, also adoption of new fuels (biogas, bio oil bio char). Also plans for utilization of field biomass and decentralized production
Turku	Supporting energy source, importance growing	One existing CHP plant will be replaced by a a multi-fuel plant cabable of combusting wood. Plans for significant increases in woodchip and biogas usage
Vaasa	Supporting energy source, already replacing fossil fuels in major power plants	Energetic utilization of wood, straw, biowaste and sludge is announced to have great potential

7 Conclusions

Development of energy systems in the analyzed case cities was noticed to be mainly based on the renewable energy, energy saving and carbon dioxide emission reduction targets of the European Union even though some of cities have set themselves higher targets. Plans for energy system development in the cities are described in various documents. The city councils of the case cities have published strategy documents on energy and climate issues as well as on environmental issues, transport and structure development. In addition to official documents of the municipalities, also various research institutes and associations have drawn up scenarios for the cities. The scope of the strategies depends on what kinds of actors are involved. In cities with private energy companies and little co-operation between the city council and the local energy company, targets may mainly limit to energy consumption reductions in municipal buildings and municipal actions as well as information campaigns. Instead, in cities with municipal energy companies or plentiful co-operation between the city and the local energy companies, energy and climate strategies often include concrete measures such as construction of new power plants or distribution infrastructure. Most strategies are based on targets for reductions of carbon dioxide emissions and improved energy efficiency and renewable energy production are seen as tools for emission reductions. Therefore for example the attractiveness of additional utilization of bioenergy depends rather heavily on how the carbon neutrality of bioenergy usage is defined.

Popular measures for reaching the energy saving targets in the case cities include for example energy efficiency improvements especially in municipal buildings. The cities themselves can also affect energy consumption by land-use planning and by improving public transportation connections and infrastructure for bicycle and pedestrian traffic. Many cities have also some new housing areas where modern solutions related to energy efficiency, distributed energy production technologies, waste management and transport systems are demonstrated.

Heating solutions based on renewable energy sources are announced to be favored especially in municipal buildings. Solar thermal systems, heat pumps, ground heat systems and biomass-based heating solutions are all promoted rather equally. However, district heating systems are planned to be expanded and favoured over other heating systems in areas with an existing network.

Some of the cities have already investigated the potential for various renewable energy production methods in the city and in the nearby area whereas in other cities further reports are needed. 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.

Different paths for sustainable development were found both in literature and in the strategies of the cities, but some general requirements can be identified for successful implementation of forerunner concepts. Suitable political framework with significant support measures and binding targets accelerate the development process. In addition to regional, national and EU-level policies, voluntary commitments to various programs and alliances with common targets are typical for forerunner cities. In many cases, the municipality has contributed significantly to the process and co-operated with other actors such as local companies and research institutes. Public interest and active commitment of citizens is also one factor that is typical for successful implementation of projects in energy and environment sector.

The analyzed 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 heavily.

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9 Appendixes

Appendix 1: Renewable energy targets for the EU's Member States

(Directive 2009/28/EC)

	Share of energy from renewable sources in gross final consumption of energy, 2005 (S_{2005})	Target for share of energy from renewable sources in gross final consumption of energy, 2020 (S_{2020})
Belgium	2,2 %	13 %
Bulgaria	9,4 %	16 %
Czech Republic	6,1 %	13 %
Denmark	17,0 %	30 %
Germany	5,8 %	18 %
Estonia	18,0 %	25 %
Ireland	3,1 %	16 %
Greece	6,9 %	18 %
Spain	8,7 %	20 %
France	10,3 %	23 %
Italy	5,2 %	17 %
Cyprus	2,9 %	13 %
Latvia	32,6 %	40 %
Lithuania	15,0 %	23 %
Luxembourg	0,9 %	11 %
Hungary	4,3 %	13 %
Malta	0,0 %	10 %
Netherlands	2,4 %	14 %
Austria	23,3 %	34 %
Poland	7,2 %	15 %
Portugal	20,5 %	31 %
Romania	17,8 %	24 %
Slovenia	16,0 %	25 %
Slovak Republic	6,7 %	14 %
Finland	28,5 %	38 %
Sweden	39,8 %	49 %
United Kingdom	1,3 %	15 %

Appendix 2: Estimated total amount of each renewable technology in Finland in 2010-2020

(Ministry of Employment and the Economy 2010)

Tables 10a and 10b

Estimation of total contribution expected from each renewable energy technology in Finland to meet the binding 2020 targets and the indicative interim trajectory for the shares of energy from renewable resources in electricity

Installed capacity (MW)	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hydro	**3040**	3050	3050	3050	3050	3050	3050	3060	3070	3080	3090	3100
<1 MW	**30**	30	30	30	30	30	30	30	30	30	30	30
1 -10 MW	**280**	280	280	280	280	280	280	280	280	280	280	280
>10MW	**2730**	2750	2750	2750	2750	2750	2750	2750	2760	2770	2780	2790
Of which pumping	**0**	0	0	0	0	0	0	0	0	0	0	0
Geothermal	**0**	0	0	0	0	0	0	0	0	0	0	0
Solar	**0**	0	0	0	0	0	0	0	0	10	10	10
photovoltaic	**0**	0	0	0	0	0	0	0	0	10	10	10
concentrated solar power	**0**	0	0	0	0	0	0	0	0	0	0	0
Tide, wave, ocean	**0**	0	0	0	0	0	10	10	10	10	10	10
Wind	**80**	170	280	380	480	580	670	1060	1440	1800	2160	2500
onshore	**80**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
offshore	**0**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	**2140**	1790	1980	2040	2090	2150	2200	2320	2450	2600	2740	2920
solid	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
biogas	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
bioliquids	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total	**5260**	5010	5310	5480	5640	5790	5940	6450	6970	7490	8000	8540
of which in CHP	**2030**	1690	1870	1930	1980	2030	2080	2190	2320	2460	2590	2760

Gross electricity generation (GWh)	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hydro	**13910**	14210	14210	14210	14210	14210	14210	14250	14290	14330	14370	14410
<1 MW	**140**	150	150	150	150	150	150	150	150	150	150	150
1 -10 MW	**1260**	1290	1290	1290	1290	1290	1290	1290	1290	1300	1300	1310
>10MW	**12510**	12780	12780	12780	12780	12780	12780	12810	12850	12890	12920	12960
Of which pumping	**0**	0	0	0	0	0	0	0	0	0	0	0
Geothermal	**0**	0	0	0	0	0	0	0	0	0	0	0
Solar	**0**	0	0	0	0	0	0	0	0	0	0	0
photovoltaic	**0**	0	0	0	0	0	0	0	0	0	0	0
concentrated solar power	**0**	0	0	0	0	0	0	0	0	0	0	0
Tide, wave, ocean	**0**	0	0	0	0	0	0	0	0	0	0	0
Wind	**150**	360	590	820	1060	1290	1520	2440	3350	4260	5180	6090
onshore	**150**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
offshore	**0**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	**9660**	8090	8910	9200	9420	9650	9880	10370	10930	11550	12150	12910
solid	**9640**	3930	4520	4760	4940	5120	5300	5730	6240	6810	7350	7860
biogas	**20**	40	40	40	50	50	50	60	60	70	70	270
bioliquids	**included in solid biomass**	4120	4350	4390	4440	4480	4530	4580	4630	4680	4730	4780
Total	**23730**	22660	23710	24230	24690	25150	25620	27060	28580	30150	31710	33420
of which in CHP	**8480**	7980	8480	8750	8980	9210	9430	9900	10440	11040	11620	12340

Appendix 3: Estimated total amount of each renewable technology in Germany in 2010-2020

(Federal Republic of Germany 2010)

Table 10a: Estimate of the total contribution (installed capacity, gross electricity consumption) anticipated in Germany of each technology using renewable energy sources with regard to the binding targets for 2020 and the indicative trajectories for the share of energy from renewable sources in the electricity sector in the period 2010-2014 [58]

	2005		2010		2011		2012		2013		2014	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Hydropower:	4 329	19687	4 052	18 000	4 068	18 000	4 088	18 000	4 111	19 000	4 137	19 000
<1MW	641	3 157	507	2 300	511	2 300	515	2 300	521	2 450	527	2 450
1 MW -10 MW	1 073	3 560	987	4 050	991	4 050	995	4 050	1 000	4 250	1 005	4 250
> 10MW	2 615	12 971	2 558	11 650	2 567	11 650	2 577	11 650	2 590	12 300	2 604	12 300
from pumped storage power plant	4 012	7 786	6 494	6 989	6 494	6 989	6 494	6 989	6 494	6 989	6 494	6 989
Geothermal energy:	0.2	0.2	10	27	17	53	27	97	40	164	57	257
Solar energy:	1 980	1 282	15 784	9 499	20 284	13 967	23 783	17 397	27 282	20 293	30 781	23 218
photovoltaics	1 980	1 282	15 784	9 499	20 284	13 967	23 783	17 397	27 282	20 293	30 781	23 218
concentrated solar energy	0	0	0	0	0	0	0	0	0	0	0	0
Tides, waves, other ocean energy:	0	0	0	0	0	0	0	0	0	0	0	0
Wind energy:	18 415	26 658	27 676	44 668	29 606	49 420	31 357	53 055	32 973	57 314	34 802	63 657
land-based	18 415	26 658	27 526	44 397	29 175	48 461	30 566	51 152	31 672	54 064	32 763	58 420
offshore	0	0	150	271	432	959	792	1 903	1 302	3 250	2 040	5 237
Biomass:	3 174	14 025	6 312	32 778	6 620	34 682	6 934	36 710	7 214	38 562	7 475	40 359
solid	2 427	10 044	3 707	17 498	3 860	18 298	4 017	19 294	4 140	20 114	4 253	20 901
biogas	693	3 652	2 368	13 829	2 523	14 933	2 680	15 966	2 837	16 998	2 985	18 008
liquid biofuels (1)	54	329	237	1 450	237	1 450	237	1 450	237	1 450	237	1 450
Overall:	27 898	61 653	53 834	104 972	60 596	116 122	66 189	125 258	71 621	135 333	77 251	146 490
from combined heat and power		-	1 067	5 328	1 280	6 453	1 503	7 681	1 740	9 002	1 990	10 424

(1) Only those are to be considered which meet the sustainability criteria of Article 5(1), last subparagraph, of Directive 2009/28/EC.

Table 10b: Estimate of the total contribution (installed capacity, gross electricity) anticipated in Germany of each technology for the use of renewable energy sources with regard to the binding targets for 2020 and the indicative trajectories for the share of energy from renewable sources in the electricity sector in the period 2015-2020 [59]

	2015		2016		2017		2018		2019		2020	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Hydropower [60] **:**	4 165	19 000	4 196	19 000	4 228	19 000	4 258	19 000	4 286	20 000	4 309	20 000
<1MW	534	2 450	539	2 450	546	2 450	552	2 450	558	2 550	564	2 550
1 MW -10 MW	1 012	4 250	1 019	4 250	1 026	4 250	1 032	4 250	1 038	4 500	1 043	4 500
>10MW	2 620	12 300	2 638	12 300	2 657	12 300	2 674	12 300	2 689	12 950	2 702	12 950
from pumped-storage power plant[61]	6 494	6 989	6 494	6 989	6 494	6 989	7 900	8 395	7 900	8 395	7 900	8 395
Geothermal energy:	79	377	107	534	142	730	185	976	236	1 281	298	1 654
Solar Energy:	34 279	26 161	37 777	29 148	41 274	32 132	44 768	35 144	48 262	38 243	51 753	41 389
photovoltaics	34 279	26 161	37 777	29 148	41 274	32 132	44 768	35 144	48 262	38 243	51 753	41 389
concentrated solar energy	0	0	0	0	0	0	0	0	0	0	0	0
Tides, waves, other ocean energy:	0	0	0	0	0	0	0	0	0	0	0	0
Wind Energy [62] **:**	36 647	69 994	38 470	76 067	40 154	82 466	41 909	89 210	43 751	96 359	45 750	104 435
land-based	33 647	61 990	34 371	64 583	34 815	66 873	35 188	68 913	35 479	70 694	35 750	72 664
offshore	3 000	8 004	4 100	11 484	5 340	15 592	6 722	20 297	8 272	25 666	10 000	31 771
Biomass:	7 721	42 090	7 976	43 729	8 211	45 299	8 440	46 761	8 648	48 133	8 825	49 457
solid	4 358	21 695	4 472	22 396	4 575	23 050	4 672	23 633	4 750	24 139	4 792	24 569
biogas	3 126	18 946	3 267	19 884	3 399	20 798	3 531	21 678	3 660	22 543	3 796	23 438
liquid biofuels (1)	237	1 450	237	1 450	237	1 450	237	1 450	237	1 450	237	1 450
Overall[63]**:**	82 891	157 623	88 526	168 479	94 009	179 626	99 561	191 092	105 183	204 016	110 934	216 935
from combined heat and power	2 250	11 937	2 530	13 533	2 823	15 220	3 129	16 986	3 444	18 837	3 765	20 791