LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Department of Energy and Environment Technology
MASTER'S THESIS

SMALL SCALE THERMAL ENERGY PRODUCTION IN HELSINKI METROPOLITAN AREA IN EMISSION TRADING POINT OF VIEW

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ALKUSANAT

Tämä työ on tehty terveyden ja hyvinvoinnin laitokselle. Kiitän terveyden ja hyvinvoinnin laitosta mahdollisuudesta tehdä diplomityö, mahtavasta työporukasta ja mukavasta työilmapiiristä. Työn ohjaajana laitoksella toimi Jouni Tuomisto, jota haluan kiittää asiantuntevista neuvoista ja kiinnostuksesta työtäni kohtaan.

Työn tarkastajana toimi professori Risto Soukka Lappeenrannan teknillisestä yliopistosta. Kiitän häntä asiantuntevasta ohjauksesta ja kiinnostuksesta työtäni kohtaan.

Lisäksi kiitän vanhempiani ja muuta perhettäni kannustuksesta työn valmiiksi saamiseksi.

27.7.2009
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TIIVISTELMÄ
Lappeenrannnan teknillinen yliopisto
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Pienimuotoinen lämmöntuotanto Helsingin metropolin alueella päästökaupan kannalta.

Diplomityö

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Tarkastajat: Risto Soukka ja Jouni Tuomisto
Hakusanat: Lämmitys, Päästöt, Päästökauppa.

Kasvihuoneilmiö asettaa vakavimman uhan ihmiskunnalle tulevaisuudessa. Tämän takia on luotu päästökauppa, jonka tarkoitus on rajoittaa ihmisen toiminnasta aiheutuvaa kasvihuoneilmiön voimistumista.

Työssä tutkittiin Helsingin seudun rakennusten lämmityksestä aiheutuvia kasvihuonekaasuja. Tutkimukseen otettiin mukaan kasvihuonekaasuista hiilidioksidi ja pienhiukkaspäästöt. Tarkastelu tehtiin pääasiassa kaukolämmityksen näkökulmasta ja tutkitaan kaukolämpöverkon laajentamisesta aiheutuvia kustannusten ja päästöjen muutoksia.

Tutkimuksen mukaan lämmityksen hiilidioksidipäästöt kasvavat noin 10 %, jos rakennusten kaukolämmityksen osuus kasvaa nykyistä tahtia. Tällöin saavutettaisiin merkittävä säästö pienhiukkaspäästöissä, noin 40 %.

Kaukolämmitys lisää hieman hiilidioksidipäästöjä, mutta vähentää pienhiukkaspäästöjä. Kaukolämmityksen laajentamiskustannukset kohdennettiin pienhiukkaspäästöjen vähentämiskustannuksiksi ja todettiin niiden olevan merkittävästi suuremmat kuin perinteisten pienhiukkaspäästöjen vähentämismenetelmien kustannukset.

Jos mahdollinen uusi ydinvoimala liitettäisiin Helsingin seudun kaukolämpöverkkoon, vähenisi hiilidioksidi ja pienhiukkaspäästöt merkittävästi. Ydinvoimalan tuotantokustannukset on laskettu olevan kilpailukykyinen muidin tuotantomenetelmiin verrattuna. Etenkin tulevaisuudessa, jolloin päästökauppa tulee nostamaan fossiilisten polttoaineiden hintoja.

ABSTRACT
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Small Scale Thermal Energy Production in Helsinki Metropolitan Area in Emission Trading Point of View

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Emission trading with greenhouse gases and green certificates are part if the climate policy the main target of which is reduce greenhouse gas emissions.

The carbon dioxide and fine particle emissions of energy production in Helsinki Metropolitan area are calculated in this study. The analysis is made mainly by district heating point of view and the changes of the district heating network are assessed.

Carbon dioxide emissions would be a bit higher, if the district heating network is expanded, but then the fine particle emissions would be much lower. Carbon dioxide emissions are roughly 10 % higher, if the district heating network is expanded at same rate as it has in past five years in the year 2030. The expansion of district heating network would decrease the fine particle emissions about 40 %.

The cost of the expansion is allocated to be reduction cost of the fine particle emissions, which is considerably higher than the traditional reduction methods costs.

The possible new nuclear plant would reduce the emissions considerably and the costs of the nuclear plant would be relatively low comparing the other energy production methods.

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SYMBOLS

SYMBOLS

A	Area	[m^2]
c_p	Specific heat capacity	[J/(gK)]
T	Temperature	[°C, K]
t	Time period	[s]
U	The overall heat transfer coefficient	[$W/(m^2K)$]
Q	Heat input or heat lost	[J]
q	Mass flow	[kg/s]

Greek symbols

α	Buildings floor area fraction of the total floor area in city
Δ	Refers to a change
ρ	Density

Sub indexes

buildings	Buildings
city	City
cold	Cold
district heating	District heating
floor	Floor
in	Indoor
out	Outdoor
thermal	Thermal energy
other heating	Other heating methods in use
w	Water
warm	Warm

superscripts

2007	Year 2007
2013	Year 2013
2025	Year 2025

2030	Year 2030
Year	Year

Abbreviations

BAT	Best technique available
CO_2	Carbon dioxide
CTP	Combined Thermal and Power plant
GWh	GigaWatthour
kJ	kilojoules
MW	MegaWatts
MJ	MegaJoules
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
PM	Particle emissions
$PM_{2.5}$	fine particle emissions
REF	Recovered Fuel
RDF	Refuse-derived Fuel
SO_2	Sulphur dioxide
TJ	TeraJoules
TWh	TeraWatthour

1. INTRODUCTION

1.1 Background

In northern countries a major proportion of greenhouse gases are produced in thermal energy production. The purpose of emission trading is to decrease the greenhouse gas emissions and thus it affects thermal energy production. In particular, in Finland this means district heating, which is widely used heating method; covering 48 % of the inhabitants and 43 % of the floor area in Finland (Adato Energia 2008, Statistics of Finland 2009).

In this study the impact of emission trading on a small scale thermal energy production in district heating network is evaluated in the Helsinki metropolitan area (Espoo, Helsinki, Kauniainen and Vantaa). Small scale thermal energy production is estimated to include all the district heating plants and stations, the total thermal output is less than 50 megawatts (MW). The emissions of other used heating methods in use are also evaluated in this study.

This assessment was made in National Institute for Health and Welfare in Kuopio in the Bioher-project, which goal is to calculate the health risks of fine particle and greenhouse emissions will have on city-level.

1.2 Purpose and boundaries

The main purpose of this study was to calculate carbon dioxide (CO_2) and fine particle emissions ($PM_{2,5}$), expected to be formed in small scale district heating plants and by the other heating methods in use in the Helsinki metropolitan area for years 2013, 2020 and 2030.

A secondary goal was to evaluate costs of emission trading for small scale energy production plants in the area and to consider whether a possible sixth nuclear plant in Finland would have a significant benefit in terms of emission or cost, if it were to produce district heat for the Helsinki Metropolitan area.

For the other heating methods in use the results will be only indicative, because of time and resource limitations of this study. There are few accurate studies or statistics about those other heating methods and fore there calculations will be based more in theory than on any studied or measured information.

2. THERMAL ENERGY PRODUCTION

Thermal energy is needed in buildings to make them more comfortable. It is used both to the heat house and to provide warm tap water. The following paragraphs describe how the need of thermal energy in buildings can be calculated and what production methods are being used in Helsinki Metropolitan area.

2.1 Need of thermal energy in buildings

Thermal energy flows of a building are shown in figure 1 (Seppänen O., 2001 s.111).

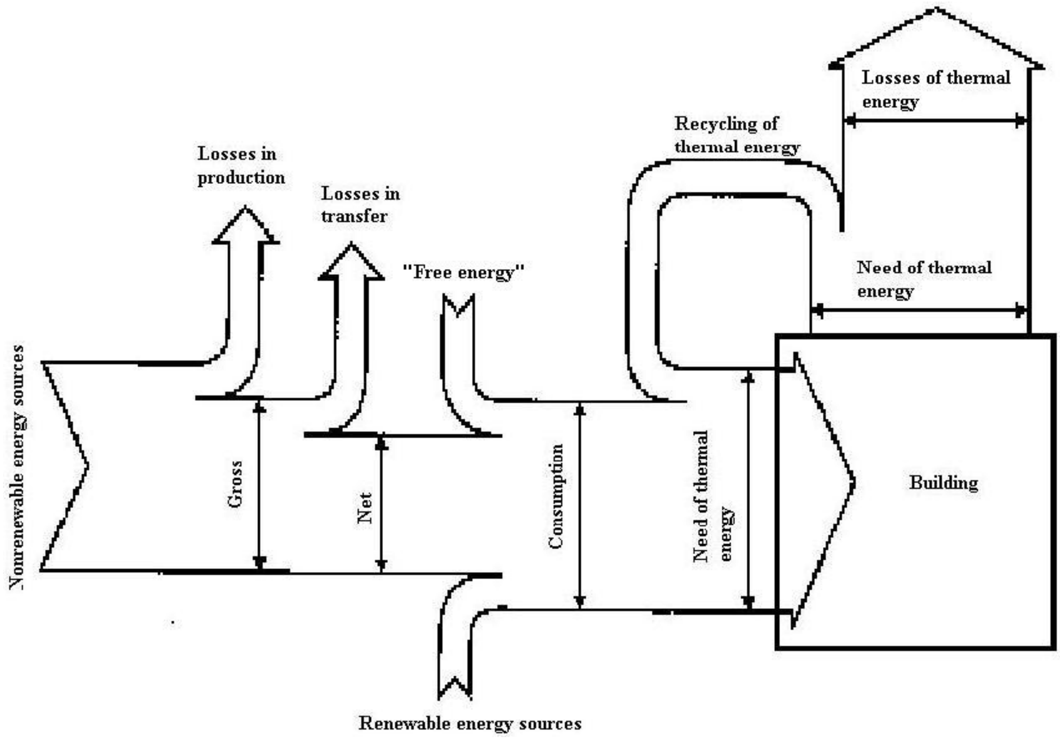

Figure 1. Buildings thermal energy flows (Seppänen O., 2001 s. 111).

As figure 1 shows the thermal energy losses in a building define the need of thermal energy of a building. It can be reduced by recycling the lost heat back into the building. Thermal energy losses are caused by energy flows, which are lost through walls, roof, floor, doors, windows and in leaks. The building structure, materials and insulation define how large the flows are through the wall, roof, floor and etc.

Errors made during the building phase can create the so called cold connection later on and this refers to a temporary reduction in insulation of a building. Cold connection can decrease indoors temperature and cause problems like cracks to the wall. This will increase thermal energy losses in a building and this is why errors in the building phase have to be avoided (Seppänen O., 2001. s 85).

Air flow through gaps and ventilation are usually thought to be the only leaks in a building, but also the less of warm tap water down into the sewers is a thermal energy leak. Air flow is caused by pressure differences between inside and outside air. Usually the difference is caused by temperature differences, wind or mechanical ventilation (Seppänen O., 2001 s. 57-110).

In addition to the thermal energy, which is spent in replacing buildings thermal energy losses, in district network some of thermal energy is lost during the transfer of heat from the thermal energy producer to the customer. Thus, the single consumer annual need of thermal energy is not only dependent on building related factors, but also external factors can influence this value. Climate and use purpose of the building also will affect need for thermal energy (Huovilainen & Koskelainen, 1982).

Calculations for need of thermal energy can be done at many accuracy levels. The simplest calculation assumes that all heat losses in a building, except tap water, will be dependent on the indoor and outdoor temperature. Need of thermal energy for certain time period can be calculated by multiplying overall heat transfer efficiency by temperature difference between indoor and the outdoor temperature and surface area of a building. This is the so called day degree method. Overall heat transfer can be calculated or estimated by using thermal density factor requirements. Finnish building regulations regulate certain thermal density factors for different parts of a building, which are listed in table 1.

Table 1. Finnish building regulation collection for thermal density factor requirements (Seppänen O., 2001. s 101, Finland's environmental administration 2008)

Part of building	1985-2001 Warm area [W / m^2 K]	1985-2001 Half warm area	2002-2007 Warm area [W / m^2 K]	2002-2007 Half warm area	2007-2010 Warm area [W / m^2 K]	2007-2010 Half warm area	2010- ? Warm area [W / m^2 K]	2010- ? Half warm area
Walls	0,28	0,45	0,25	0,45	0,24	0,38	0,17	0,26
Roof	0,22	0,45	0,16	0,45	0,16	0,28	0,09	0,14
Floor	0,22	0,45	0,16	0,45	0,19	0,28	0,17	0,26
Part which is against ground	0,36	0,45	0,25	0,45	0,24	0,34	0,16	0,24
Window	2,1	3,1	1,4	2,1	1,4	1,8	1	1,4
Door	0,7	2,9	1,4	2,1	1,4	1,8	1	1,4

Thermal energy, which is lost through floor, walls, windows, doors and roof, can be calculated by equation 1 in the day degree method (Seppänen O., 2001. p 112).

$$Q_i = UA(T_{out} - T_{in})\Delta t \,, \qquad (1)$$

where Q_i = Heat flow from building to surroundings,

U = Buildings overall heat transfer coefficient,

A = Area to be heated,

T_{out} = Outdoor temperature,

T_{in} = Indoor temperature and

Δt = Time period.

The weak point of the day degree method is that it does not take into account the free energy sources like sun, electrical machines, humans and lights. So in calculations indoor temperature is set to be somewhat lower than in reality, often a temperature of 17 °C is used, and thermal energy from free energy sources is estimated to cover the difference between the real and calculated need of thermal energy of a building (Seppänen O., 2001. p 111-114).

The day degree method is used in this study to calculate the total need of thermal energy in Helsinki Metropolitan area. More accurate calculation methods would require more information about the buildings and thermal energies in the area which were not possible due to time and resource limitations.

The thermal energy, which is needed to heat tap water, can be calculated by equation 2 (Seppänen O., 2001. p 111-114).

$$Q_{i,w} = \rho_w c_{pw} q_w (T_{warm} - T_{cold}) \Delta t \,, \qquad (2)$$

where $Q_{i,w}$ = Thermal energy needed for warm tap water,

ρ_w = Water density,

c_{pw} = Specific heat capacity for water,

q_w = Consumption of warm tap water,

T_{warm} = Temperature of warm tap water and

T_{cold} = Temperature of cold tap water.

Other thermal energy losses in buildings are estimated to be negligible in this study. The one year need of thermal energy in a city can be then estimated to be sum of single building needs of thermal energy. Thus a city's need of thermal energy can be calculated by equation 3.

$$Q_{city}^{year} = \sum U_{Buildings} A_{floor} (T_{out} - T_{in}) + \sum \rho_w c_{pw} q_w (T_{warm} - T_{cold}) \,, \qquad (3)$$

where Q_{city}^{year} = Year need of thermal energy in city,

$U_{Buildings}$ = The overall heat transfer coefficient in buildings per floor area in city and

A_{floor} = Floor area of buildings in city.

2.2 District heating

District heating is an efficient method to produce thermal energy in cities and population centres. The fundamental idea is to produce centrally needed thermal energy for the area. This means customers and energy production plants are connected to each other in a grid. In this study the purpose is not to examine the grid precisely, only to present in general terms the district heating network structure and adjustments.

A single apartment need of thermal energy could be supplied by a warm tap water condenser, because the amount of energy, which is needed to increase indoor temperature of a house, is negligible compared to energy, which is needed to heat tap water. The thermal energy needed to increase indoor temperature, fraction of needed thermal energy increases, when there are more and more apartments, for example in an apartment house. The need of thermal energy in multiple apartments is less than sum of single apartments. The difference is caused by desynchronized use of warm tap water (Huovilainen & Koskelainen, 1982).

The customer’s connection to a district heating network can be achieved in two ways: 1) open cycle and 2) closed cycle systems. In the open cycle system, a fraction or all the water, which flows in district heating network, is utilized in thermal energy transferring system and it will be consumed in the destination. This means that warm tap water will be taken directly from the district heating network and transferred into the sewers after use (Huovilainen & Koskelainen, 1982).

In a closed circle system, there are destined water flows in thermal energy transferring system than in district heating network and the water in the network is not be consumed at its destination but will be returned to the network. This means there is a condenser between the customer and district heating network, which will transfer the needed energy to customer. Closed circle connections are mainly used in Finland (Huovilainen & Koskelainen, 1982).

The need of thermal energy in district heating network has to be specified in the building phase. The need for thermal energy can be calculated or estimated. Usually it is based on estimations, because often there is no accurate information about the number of future apartments or how much energy the customers will consume.

Transferred thermal energy is controlled mainly by controlling the outgoing water temperature in thermal energy production units. This outgoing water temperature is often set to be dependent on the outdoor temperature. The heat durability of the pipes defines the limit-value for outgoing water temperature. In addition, pressure differences and static pressure have to be controlled in the district heating network. These adjustments and their implementation methods are dependent of each others.

The main district heating network adjustment factor is the consumer’s need of thermal energy. The thermal energy provider has to guarantee a specific pressure difference and a definite thermal energy output in the network to ensure that customer can obtain the necessary thermal energy from the network. Excessive high pressure differences or thermal energy output in the network will cause higher energy losses in the network and thus have to be avoided. The pressure difference in whole network also has to be adjusted, so to ensure that they do not damage the devices. Thus, one must ensure that the flowing water temperature will not go over the boiling temperature and vaporization will not occur in the network. The static pressure in the network has to be adjusted to ensure that it is higher than the vaporization pressure.

The temperature of outgoing water adjusting is achieved by mixing hot water from a boiler with flowing water in the network until the desired water temperature is obtained in the heat-only boiler station. Adjustments for pressure differences and static pressure are mainly done by pumps. These pumps are controlled in two ways: by throttles or by adjusting pumps tacks. Regulators are not needed if throttles are used in the heat-only boiling stations, because consumers simply need to adjust the warm water flow to obtain needed thermal energy. Throttling ensures that most of the thermal energy is committed to the water. However, adjusting the pumps tacks are significantly cheaper than throttling devises (Huovilainen & Koskelainen 1982).

Thermal energy production plants connection to the district heating network can be simplified in two ways; direct and indirect techniques. The direct connection means, that the same water flows in district heating network as in boiler. This method is mostly used in small scale energy production plants. It is quite cheap to make, but on the other hand, it will place some restrictions on the fuels and boiler temperatures.

The indirect connection means that in the thermal energy production plant boiler uses different water than in district heating network. The plant and district heating network are connected by a condenser. There are many kinds of condensers, but the main idea is that the two water flows do not physically mix together. The indirect connection is mostly used in larger steam turbine plants, but it can also be used in small scale plants (Huovilainen & Koskelainen 1982).

2.2.1 Regulations for district heating plants

Directive for protecting environment and lowering emissions, the so called IPPC – directive, requires information exchange between countries and industry of best available technique (BAT). Based on this information exchange, BAT-correlation documents are formed, so called BREF- documents (BAT Reference Documents), which were made for large scale energy production plants in the year 2004. BREFs for small scale energy production plants are still not available. Finnish environmental law requires the use of best technique available. Old air pollution law applied to small scale energy production plant cases, this law dates from year 1987. Emissions caps do not apply to current techniques, so there have been diverse permission policies for small scale energy production plants in the last years (Jalovaara et al. 2003).

In 2003, the national assessment for BAT-technique for Finnish 5-50 MW energy production plants was made for uniting the permission policy. BAT-levels are not emission caps; they are only intended to help the authorities to set emission caps when the local conditions are taken into account (Jalovaara et al. 2003).

Finnish environmental law (86/2000) 20 § requires that any action, which is or may be dangerous to environment, must be conducted only after permission has been granted. Actions that require permission are described more closely in the Finnish environmental regulation 1 § (169/2000), where energy production is mentioned in part three. Part three divides in two parts; to nuclear plants and to oil, mineral coal, wood, peat, gas or other flammable material using combustion plants, of which total potential fuel energy output is over 5 MW or which used total potential fuel energy output in a year is at least 54 terajoules (TJ). Energy production plant may have more than one boiler and permission will be given applying combined total potential fuel energy output of the boilers. If the total potential fuel energy output is less than mentioned above, but the plant is located in ground water area, it will require permission as well.

Environmental regulation third moment mentions also, that landfill and disposal plants such as incineration plants requires a permission also.

Authorities permit jurisdiction is regulated in environmental protection regulation second moment. It says that community council will handle permissions, if energy production plant total fuel energy output potential is over 5 MW but less than 50 MW. Over 50 and less than 300 MW plants permissions handles the aerial environmental administrations. Over 300 MW plants permissions will be handled in environmental permission agency (Jalovaara et al.. 2003).

In 41 § of environmental protection regulation are closer regulations for already exiting 5-50 MW plants and in 43 § for large scale energy production units statutory permission procedure. For small scale plants there is only one emission norm (Finnish government decision 157-1987), which is for particle emission and does not fulfil the BAT- requirements (Jalovaara et al.. 2003).

2.2.2 Small scale district heating units

Total fuel consumption of energy production plants was 580 PJ in Finland in year 2001 and 13 % of this was used in plants producing less than 50 MW energy. Numerically there are 1400 energy productions plants, fuel energy output is less than 50 MW, and about 200 larger plants in Finland (Jalovaara et al.. 2003). A Significant number of these small scale energy production plants are backup and peak heating units, which are not constantly in use during the year. Table 2 shows the fuels used in small scale plants.

Table 2. Fuels consumption in plants producing less than 50 MW plants in year 2001. (Jalovaara et al.. 2003)

	Mineral coal	**Heavy fuel oil**	**Light fuel oil**	**Natural gas**	**Peat**	**Wood**	**other**	**Tot al**
[TWh]	0,8	5,1	0,2	4,4	2,0	4,6	3,3	20,4
[%]	4	25	1	22	10	23	16	100

Other fuels in table 2 are mostly fuels from industrial processes, like waste- and biogas, coke, pine oil, hydrogen and solid fuels. These can be burned as either the main or a supplementary fuel.

Small or medium scale energy production plants are either heat-only and vapour production stations or backpressure power plants, which produce combination of electricity and heat or vapour. With respect to these small scale energy production plants, there are technically none, which are electricity-only production plants (Jalovaara et al. 2003).

Most of the fuel consumption takes place in large scale energy production plants in energy production and most of them also have efficient flue gas cleaning system, so emissions per produced energy are lower than in small scale plants. Conversely to potential to reduce emissions in small scale plants is greater, because of authorities have not demanded installations of efficient emission reduction systems as in larger plants.

A fine particle assessment for energy production was made and the possibility to reduce fine particle ($PM_{2.5}$) emissions was evaluated in year 2007. In that report it was calculated that less than 5 MW plants account for almost half the fine particles emissions of energy production in Finland, even though they use only 4 % of the sector's total fuel. In that assessment, reduction potential of $PM_{2,5}$-emission of small scale plants was estimated to be 40 % of whole energy production potential (Karvosenoja et al.. 2007).

Most of boiler-types in use small scale energy production plants are burner, grate and bubbling fluidized bed boilers. Burners can be used also in grate boilers, which permit an additional fuel use, like natural gas or heavy/light fuel oil.

Heat-only or vapour production stations do not produce electricity and their operation efficiency in these plants are high, as much as 85 - 93 %. Flue gas losses are responsible for the greatest efficiency loss in these stations (Jalovaara et al. 2003). These are the most common small scale energy production plant types in Finland e.g. in the Helsinki Metropolitan area.

Backpressure power plants are traditionally industry- and district heating plants, which produce both heat and electricity. These power plants are adjusted so they will produce the required thermal energy and electricity is produced as a side benefit. The operation efficiencies are typically 80 - 85 % in industry and 85-90 % in district heating plants. The ratio between produced thermal energy and electricity is about 0,2 - 0,3 for industry and 0,45 - 0,55 for district heating plants (Jalovaara et al. 2003)

Gas turbine-/gas motor-/ diesel motor boilers are also a solution used by some small scale plants. These plants produce thermal energy, steam to be used in some industrial process or both. The ratio between produced thermal energy and electricity often is 0,5 - 0,6 and total operation efficiency 80 - 85 % for a gas turbine boiler, if it is linked with an incineration plant. For a similar motor boiler plant the ratio is 0,9 and total operation efficiency is 90 % (Jalovaara et al. 2003).

Woodchip and peat are the most main fuels used in small scale energy production plants in Finland. Many plants use mineral coal, refined municipal waste, heavy fuel oil or different waste- and production gases. The boilers type defines which fuels can be used in the plant.

Solid fuels consist roughly three different parts; water, the flammable part and inflammable inorganic material. Flammable material is the most important part and the two others parts are weakening factors in terms of combustion. Flammable material components are carbon, hydrogen, nitrogen, sulphur and oxygen. The amount of energy is released in the combustion, depends in the carbon and hydrogen fractions in fuel. Sulphur and nitrogen, which the fuel contains, are significant originators of greenhouse emissions. Fuel will also contain trace elements, but their fractions are less than 0.1 % of the fuel of mass (Raiko et al. 2002). Typical thermal values for fuels are listed in table three.

Table 3. Typical thermal values for different fuels (Kara 1999, KorkiaAho et al. 1995).

Fuel	**Thermal value**	**Unit**	**Dampness %**	**Ash content**
Heavy oil	41,1	MJ/kg	0,5	0,04
Light oil	42,7	MJ/kg	0,02	0,01
Mineral coal	24,8	MJ/kg	10	14
Shreded peat	9,66	MJ/kg	48,5	5,1
Industrial woodchips	8	MJ/kg	55	2
Saw dust	8	MJ/kg	53	0,5
Bark of softwood	7	MJ/kg	58	2
Natural gas	35,6	MJ/kg	-	-
Biogas	15,8	MJ/kg	2	
Recycling fuel	16	MJ/kg	25	5

Plants, which use solid fuels, often use supplementary fuels, often its use is dependent an accessibility or/and price of the supplementary fuel. The most commonly used supplementary fuels are mineral coal, recycling fuels and heavy fuel oil.

Mineral coal is not used as the main fuel in small scale energy production plants in Finland usually, but often it is used as a supplementary fuel, though coal use does require an efficient flue gas cleaning system. The sulphur content of coal varies according to its country of origin. In Finland it is specified that sulphur content cap of coal should be no more than 1 % (96/61/EY). Due to the high ash content, about 10 % of the coal mass, coal burning creates high particle emissions and because ash contains heavy metals, its heavy metal emissions are also high (Lahtinen & Kompula 1995).

Municipal waste and fuels consisting of the municipal waste in recycling process are also used mainly as a supplementary fuel in small scale energy production plants in Finland. REF (REcovered Fuel) and RDF (Refuse-Derived Fuel) are the main fuels created out of municipal waste. Use of REF or RDF sets certain demands on the flue gas cleaning system. An incineration directive came into effect at the end of year 2005, which restricts emissions from incineration plants to the same low level. This has restricted the exclusive use of municipal waste fuels in small scale energy production plants, since flue gas measurement and cleaning commitments would increase expenses prohibitively.

Heavy fuel oil is most suitable for solid fuel boilers as a backup or a supplementary fuel, because it has got both good accessibility and a high thermal value. Oil burning in a grate boiler plant requires separate burner. Oil has quite a low ash content, so particle emissions are mainly from unburned carbon hydrogen compounds and coke; emissions are mainly fine particles (Lahtinen & Kompula 1995).

Tables 4 and 5 list the fuel characteristics and typical emission factors of power plants producing less than 50 MW in Finland. Some of the factors are controlled by emission reduction technique like Electro-static precipitator (ESP), cyclones or Low-NO_x-burners.

Table 4. Typical carbon dioxide factors for fuels (Kivihiilitoimikunta 2004)

Fuel	**Carbon dioxide factor [g CO2/MJ$_{fuel}$]**
Mineral coal	94
Natural gas	45
Heavy fuel oil	77
Light fuel oil	74
Shreded peat	106
Woodchips	114

Table 5. Typical emission factors for small scale energy production plants in Finland (Jalovaara et al.. 2003)

Boiler type / Fuel	**Fuels thermal energy output in the plant [MW]**	**NO_x [mg/MJ]**	**SO_2 [mg/MJ]**	**Dust [mg/MJ]**
Burner				
Heavy fuel oil	<5	150-250	350-500	20-90
(some of the plants have Low-Nox burners	5-15	150-250	350-500	10-70
	15-50	120-200	350-500	5-40
Light fuel Oil	<5	100-150	50-70	<10
(some of the plants have Low-Nox burners	5-15	100-150	50-70	<10
	15-50	60-120	50-70	<10
Natural gas	<5	60-100	0	0
(some of the plants have Low-Nox burners	5-15	60-100	0	0
	15-50	40-80	0	0

Fluidized bed boiler (ESP)				
Peat	5-10	150-200	150-250	10-50
	10-50	130-200	150-250	5-20
Wood	5-0	80-150	<30	10-70
	10-50	80-150	<30	5-30
Circulation fluidized bed boiler (ESP)				
Peat	20-50	80-150	150-250	5-20
Wood	20-40	70-120	<30	5-30
Grate (ESP + Cyclone)				
Peat	<5	150-250	150-250	20-150
	5-10	150-250	150-250	5-120
	10-50	140-220	150-250	5-100
Wood	<5	80-200	<30	20-150
	5-10	80-200	<30	20-150
	10-50	70-150	<30	10-150
Coal	5-10	70-150	400-600	400-600
	25-40	80-200	5-50	5-50

Small scale district heating plants in the Helsinki metropolitan area are mainly burner type heat-only stations, which use heavy fuel oil or natural gas. Some of them have cyclones and emulators, but some do not have any flue gas cleaning systems at all, because particle emissions are low if natural gas is being burned.

2.2.3 Large scale district heating units

In this study, district heating units, which have a thermal output of fuel over 50 MW, are estimated to be large scale district heating units. District heating produced 31,9 TWh thermal energy in 2008, of which 74 % was produced in combined power and heat (CHP) plants (Energiateollisuus 2009a). Larger thermal energy production plants are usually CHP-plants, because they are more efficient than separate energy production plants. Almost all, 95 %, of Finnish CHP-plants are listed in District Heating statistics. For the Helsinki Metropolitan area, large scale district heating units power and thermal energy production potential are presented in table 6 (Vehviläinen et al. 2007).

Table 6 Capacity of large scale energy production units in Helsinki Metropolitan area (Adato energia oy, 2008).

	CHP-plants [MW]	**Separate heat production units [MW]**	**Total thermal energy output [MW]**	**Power output [MW]**
District heating companies	1 717,0	3 645,1	5 362,1	1 340,0

Nowadays CHP-production is mainly achieved in a large coal or peat burning steam turbine with a combined cycle gas turbine power (CCGT) plant now days in Finland. About half of the power capacity and two thirds of the thermal capacity are based on counter pressure steam turbine technology as required by the EU CHP directive. Combined cycle gas turbines are used in electricity production; their electricity output is higher than can be achieved with extracting steam turbines. In thermal energy production extracting steam turbines are second-highest production technology in terms of capacity. CHP-technologies and production use in Finland 2005 are listed in table 7.

Table 7. Capacity and production of CHP-technologies in Finland 2005(Vehviläinen et al. 2007).

Capacity and production of CHP-technologies in 2005	Capacity [MW]		Productio n [TWh]	
	Thermal energy	Electri city	Thermal energy	Electri city
Combined cycle gas turbines	1 857	1 538	10,5	9,5
Backpressure turbines	10 593	2 830	46,6	11,9
Extracting turbines	2 572	1 102	11,2	5,3
Combined cycle gas turbines with modifications	537	292	1	0,6
Combustion motors	91	70	0,1	0,1
Total	15 650	5 832	69	27

Net production of district heating is presented in figure 2.

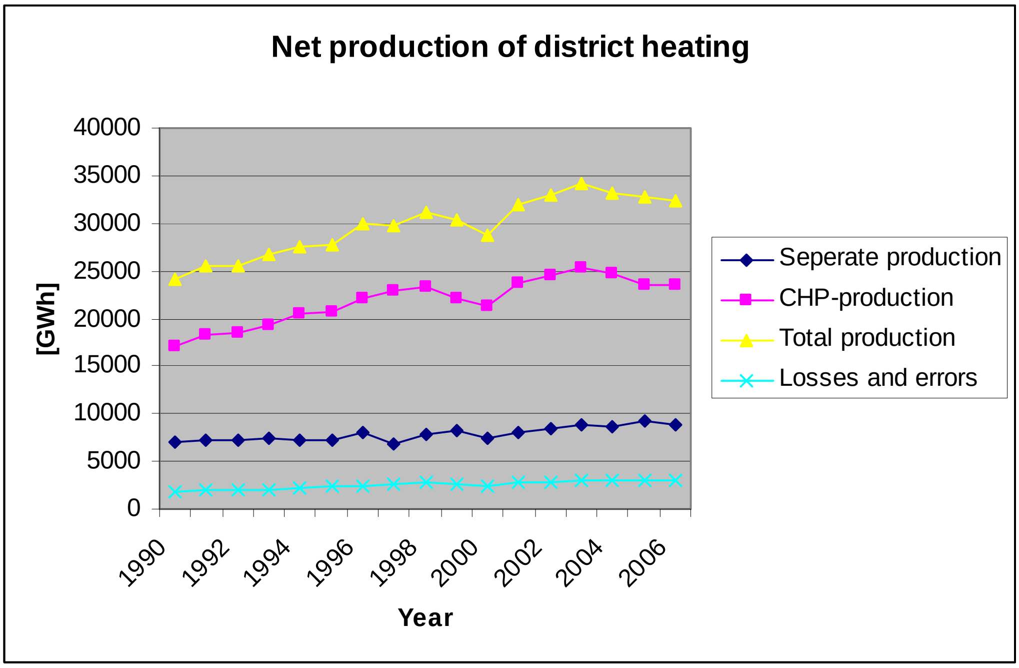

Figure 2. Net production of district heating in Finland.

In the Helsinki Metropolitan area there are two natural gas and four coal using CHP-units. The types of turbine used in these plants are backpressure turbines in coal units and combined cycle gas turbine turbines in natural gas units (Adato energia oy 2008).

CHP-plants produced 93 % of district heating in Helsinki, 60-70 % in Espoo and 87,7 % in Vantaa. Large scale energy production plants produced over 99 % of district heating in Helsinki, 97 % in Espoo and 93,1 % in Vantaa (Helsingin energia 2008, Fortum Heat and Power Oy 2008a, Vantaan energia 2008).

2.2.4 Heat storing

Consumption of thermal energy is not steady throughout the year, there is not only short term but also long term variation. Long term variations mean monthly changes in the need of thermal energy and those are caused by changes in outdoor temperatures. Short term variations refer to hourly changes in the need for thermal heating and those are affected by weather condition changes and changes in use of warm tap water.

The load on heat-only boiler plants thermal energy production can be reduced by storing the thermal energy in the district heating network or separate heat storage. Heat storing has many benefits:

- Power production increase when recharging heat storage.

- Adjustable power production.

- Lower district heating energy production costs by storing heat when production costs are lower and discharging it when costs are higher.

- Replaces energy, which is lost in a backpressure plant or in a heat-only boiler plant during planned or unplanned shutdown.

- Reduces need of thermal energy peak plants.

- It is a cleaner way to produce thermal energy in heat-only boiler plants.

A water filled tank is most suitable for short time thermal energy storage, where water acts as the mass which binds thermal energy and also as a heat transferring fluid. Water has heat storing capability of 1.16 kWh/m^3,°C. Warm water will settle on top of cold water in the tank, because of density differences.

Heat storages can be connected to the district heating network in two ways; directly, when the water in the district heating network will flow through the storage and indirectly, when water in the storage and in district heating network do not mix (Sipilä, Kari. 1985).

2.3 Other used heating methods in Helsinki Metropolitan area

In this study other heating methods refers to all the thermal energy production methods in buildings, which are not connected to the district heating network. Other heating methods are more often used in rural areas in Finland, where distances are greater between buildings and district heating is not economically feasible.

Thermal energy is produced in many ways and from many fuels. Industries and other building, which have a greater need of thermal energy, usually use the same kind of boilers as in district heating stations, only the variation between fuels and thermal energy use is larger. Their emissions are also regulated by law and emission trading affects them also, if their thermal energy production is high enough (Jalovaara et al. 2003).

Thermal energy production in residential buildings can be estimated to be so called domestic combustion. In addition to combustion processes, electrical heating is also used to heat a large of residential buildings (Statistics of Finland 2008). Domestic combustion refers to thermal energy production in a residential building, which thermal capacity of the boiler or the stove is typically below 100 kW_{th}. In Finland the most common domestic heating fuels are wood and light fuel oil, with 41.0 and 33.0 PJ in 2004, respectively (Statistics Finland 2005). Primary particle emissions from light fuel oil use are low, typically below 2 mg/MJ in a well equationing domestic boiler (Tissari et al. 2005).

2.3.1 Domestic combustion

Wood is often used as primary and supplementary fuel in detached residential houses. An over-fire type batch-burning log boiler is the most common boiler in Finland. Over-fire boilers take their air supply from below the batch through a grate by natural draught, and combustion takes place directly on top of the batch in a combustion chamber. The structure is simple, investment costs lower and emissions typically higher than in under-fire type boilers, which are more common in Sweden and Central Europe. Operation at lower loads may cause problems to the air supply to the combustion chamber and this leads to lower efficiency and higher emissions. Emission measurements for log boilers without an accumulator have been made in Sweden 2005 (Johansson et al. 2005). Total suspended particle (TSP) emission factors were between 350 and 2200 mg/MJ, with the average 900 mg/MJ. The majority of particle mass in domestic wood combustion emissions are in the size range from 0.1 to 1 µm, and $PM_{2.5}$ particles account for more than 90 % of TSP (Boman 2005). Roughly one third of log boilers use in Finland are not equipped with accumulators (Karvosenoja et al.. 2006)

Automatically feed woodchip and pellet boilers are less common than log boilers at the moment in Finland. Woodchip boilers are used mainly in rural areas. Pellet combustion has rapidly become been popular in recent years, but it still has minor importance in Finland. A continuous combustion process in fed automatically boilers is easier and more flexible to control than batch-loaded combustion. The primary particle emissions are also lower in automatically fed boilers, for pellet and woodchip boilers they are typically below 40 and 60 mg_{TSP}/MJ, (Tissari et al. 2005). In particular, pellet boilers can be used without accumulators and still achieve low emissions (Johansson 2002).

Karvosenoja et al. 2004) and in a number of other studies, where a more general

2.3.2 Industrial heating

Industries need thermal energy and vapour for their factories and they use the same kind of boilers as district heating plants and stations (Jalovaara et al. 2003). Fuels in industry boilers are somewhat different than that is used in district heating plants and stations. Table 8 lists the most widely used fuels and produced heat by industry plants in Finland (Statistics of Finland: Environment and energy 2008).

Table 8. Industries produced heat by used fuel (Statistics of Finland: Environment and energy 2008).

Source of energy	GWh	Percentage of total industry used energy
Refinery gas	7 260,3	4,0
Light fuel oil (heating fuel oil)	2 295,5	1,3
Heavy fuel oil, sulphur content < 1%	3 009,7	1,7
Heavy fuel oil, sulphur content = 1%	1 622,4	0,9
Coke [1)]	6 238,4	3,5
Blast furnace gas	4 804,9	2,7
Natural gas	16 835,5	9,3
Milled peat	4 286,6	2,4
Bark	8 386,7	4,6
Black liquor and other concentrated liquors	38 284,7	21,2
Electricity	39 361,1	21,8
District heat	2 967,3	1,6

Other	45 168,4	25,0
	180	
Total	521,5	100,0

1) Includes coke intake into blast furnace and other coke consumption by industry. Energy content of coke has been subtracted from the energy content of the produced blast furnace gas.

As table 8 shows, black liquor and electricity are most used heating methods in Finland. In Helsinki Metropolitan area industries mainly use heavy fuel oil for thermal energy production (Statistics of Finland 2008). Industries use mainly heavy fuel oil and electricity to produce needed thermal energy in Helsinki Metropolitan area (Statistics of Finland 2008).

2.4 EU Emissions Trading System

The aim of the EU Emissions Trading System (EU ETS) is to help EU Member States achieve their commitments to limit or reduce greenhouse gas emissions in a cost-effective way. It currently covers over 10,000 installations in the energy and industrial sectors which are collectively responsible for close to half of the EU's emissions of CO_2 and 40% of its total greenhouse gas emissions.

The EU ETS is a cap and trade- system, that is to say it caps the overall level of emissions allowed but, within that limit, allows participants in the system to buy and sell allowances as they require. These allowances are the common trading currency at the heart of the system. One allowance gives the holder the right to emit one tonne of CO_2. The cap on the total number of allowances is what creates scarcity in the market.

At present, for each trading period less than the scheme, Member States draw up national allocation plans (NAPs) which determine their total level of ETS emissions and how many emission allowances each installation in their country will receive. Companies that keep their emissions below the level of their allowances can sell their excess allowances. Those installations facing difficulty in keeping their emissions in line with their allowances have three choices; reduce their own emissions, buy the extra allowances they need on the market or a combination of the two. These choices are likely to be determined by relative costs.

2.4.1 Phase three emission caps

There will not be further national allocation plans in phase three. In their NAPs for the first and the second trading periods, Member States determined the total quantity of allowances to be issued and how these would be allocated to the installations concerned.

The rules for calculating the EU-wide cap are set out in the proposal. From 2013, the total number of allowances should decrease annually in a linear manner. The starting point of this line is the average total quantity of allowances in phase 2. The linear factor determining that the annual amount shall decrease is 1.74 % in relation to the phase 2 cap.

The linear factor of 1.74 % used to determine the phase 3 cap will continue to apply beyond the end of the trading period in 2020 and will determine the cap for the fourth trading period and beyond (European Union 2008). The annual ETS cap figures for the period 2013 to 2020 are listed in table 9

Table 9. Annual ETS cap figures for carbon dioxide for the period 2013 to 2020 (European Union 2008).

Year	Mio t CO2
2013	1,974
2014	1,937
2015	1,901
2016	1,.865
2017	1,829

2018	1,792
2019	1,756
2020	1,72

The reduced emission allowances in the future is estimated to make emission rights price more expensive and in 2030 emission right price is estimated to have risen to 31 €/t_{CO2}, Where as in 2008 is estimated to be 21 €/t_{CO2} (Anttila et al., 2008). In this study emission right price is estimated to be 23 €/t_{CO2}.

3. CASE: HEATING IN HELSINKI METROPOLITAN AREA

District heating network of Helsinki Metropolitan area is provided by three companies; Helsingin Energia, Vantaan Energia and Fortum Power and Heat Oy, Espoo. These companies have 45 heat production units, about which 14 are small scale units. Connected to main district heating network there are 10 small scale units. Table 12 despicts all the small scale units which are in Helsinki Metropolitan Area and their base information (Adato Energia Oy 2008).

Table 12. Small scale district heating units in Helsinki Metropolitan Area (Adato Energia Oy 2008).

DISTRICT HEATING COMPANY AND NAME OF THE PRODUCTION UNIT	**Year started up**	**Total heat output [MW]**	**Power output [MW]**	**Main fuel**
Helsingin Energia				
Salmisaari	1977	8	-	heavy fuel oil
Helsinki-Vantaa airport				
Heat-only station	1976	32	-	heavy fuel oil
Vantaan Energia Oy				
Pähkinärinne	1974	46,6	-	heavy fuel oil
Metsola	1977	17,4	-	heavy fuel oil
Katriina	1990	3,6	-	biogas
Katriina	1994	0,6	0,4	biogas
Fortum Power and Heat Oy, Espoo				
Suomenoja 4	1989	35	-	natural gas
Auroranportti	1998	15	-	light fuel oil
Juvanmalmi	2000	15	-	natural gas
Kalajärvi	2000	5	-	natural gas

These units are basically one or groups of boilers from the flue gases are emitted via the same pipe. Some of these units are located at the same address as some other unit and usually they are considered as one plant or station. In Helsinki Metropolitan Area, there are 6 power plants and 29 heat-only stations (Aarnio et al. 2008).

Use of the district and other used heating methods in different building types in Helsinki Metropolitan area are presented in figure 3.

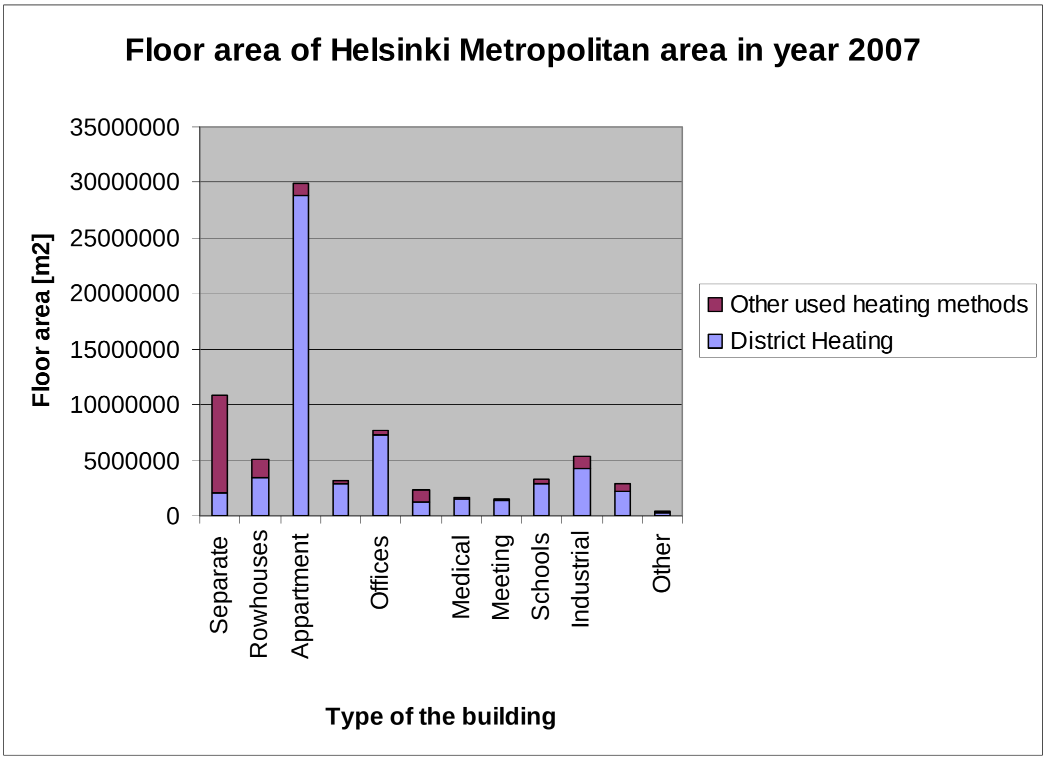

Figure 3. Use of district and other heating methods in Helsinki Metropolitan area buildings (Statistics of Finland 2008).

District heating is the most common heating method except in district residential houses as figure 3 shows. The major heating sources of other used heating methods area are electricity heating and light fuel oil heating in Helsinki metropolitan, which combined provides thermal energy for to 82 % of the other heating methods according to floor area. Floor area of the other heating methods in use and the heat sources in 2007 are shown in figure 4 (Statistict of Finland 2008).

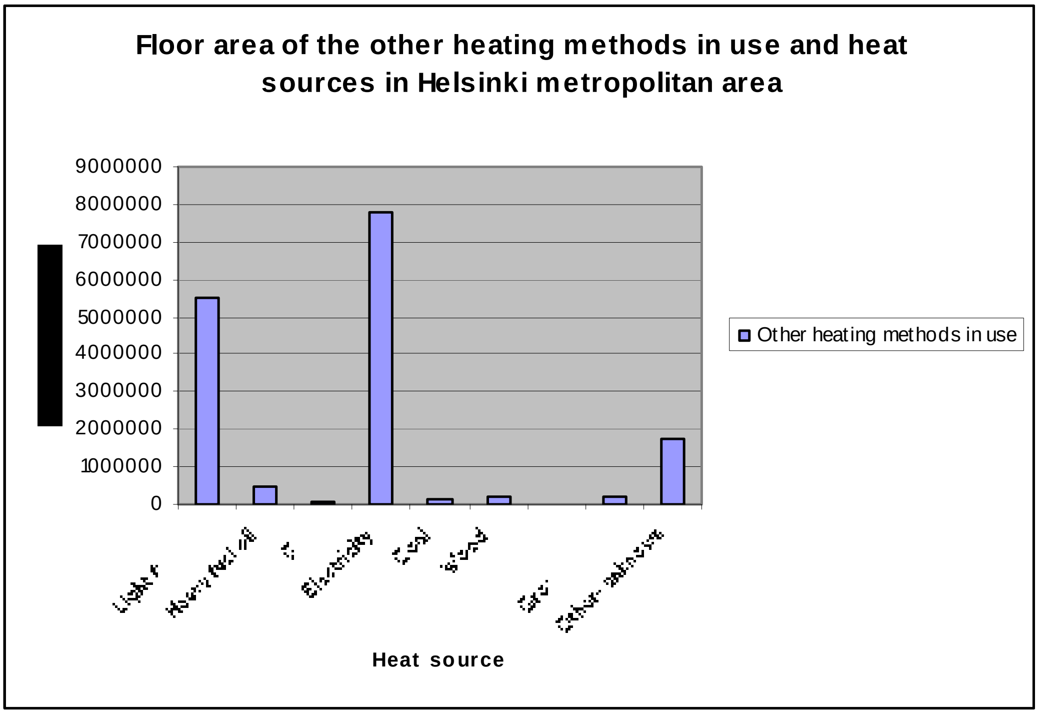

Figure 4. Floor area of the other heating methods in use subdivided according to heat source in Helsinki metropolitan area (Statistics of Finland 2008).

In this study, supplementary thermal energy production in use to heat other buildings is estimated to be from wood and any other supplementary thermal energy production is estimated to be negligible. Supplementary thermal energy production is taken into account on emission calculations in chapter 3,2.

Heating is accomplished mainly by district heating in Uusimaa-region. Table 13 lists the population in Uusimaa-region and inhabitants, living in buildings heated by district heating.

Table 13. Population in district heating houses 31.12.2007 (Adato Energia Oy 2008).

UUSIMAA	District heating company	Population in DH houses 31.12.2007	Total population 31.12.2007	Percentage of population [%]
		951 180	1 388 964	68
Espoo	Fortum Power and Heat Oy, Espoo	184 500	238 047	78
Hanko	Fortum Power and Heat Oy, Hanko	570	9 708	6
Helsinki	Helsingin Energia	526 000	568 531	93
Hyvinkää	Hyvinkään Lämpövoima Oy	35 300	44 652	79
Inkoo	Fortum Power and Heat Oy, Inkoo	820	5 460	15
Järvenpää	Fortum Power and Heat Oy, Järvenpää	22 200	37 989	58
Karjaa	Fortum Power and Heat Oy, Karjaa	..	9 044	..
Karkkila	Keravan Energia Oy, Karkkila	..	8 996	..
Kauniainen	Fortum Power and Heat Oy, Kauniainen	6 400	8 511	75
Kerava	Keravan Energia Oy, Kerava	..	33 181	..
Kirkkonummi	Fortum Power and Heat Oy, Kirkkonummi (keskusta)	10 500	35 141	30
Lohja	Lohjan Energiahuolto Oy Loher	..	37 352	..
Mäntsälä	Mäntsälän Sähkö Oy	2 190	18 980	12
Nurmijärvi	Nurmijärven Sähkö Oy	..	38 633	..
Siuntio	Fortum Power and Heat Oy, Siuntio	..	5 780	..
Tammisaari	Ekenäs Energi	..	14 784	..
Tuusula	Fortum Power and Heat Oy, Tuusula	11 100	35 968	31
Vantaa	Vantaan Energia Oy	151 600	192 522	79

As the table 13 shows, most of the inhabitants in Uusimaa-region are living in district heating houses. District heating is produced mainly from natural gas and coal utilizing in CHP-power plants as table 14.

Table 14. Fuel use in district heating units of Fortum Heat and Power Oy, Helsingin Energia and Vantaan Energia Oy.

DISTRICT HEATING COMPANY	Coal [GWh]	Heavy fuel oil [GWh]	Light fuel oil [GWh]	Natural gas [GWh]	Biogas [GWh]	Heat produced by heat pumps [GWh]	Total fuel energy consumed [GWh]
Fortum Power and Heat Oy, Espoo	1798	145	8	1300	174	0	3424
Helsingin Energia	5625	204	0	7664	1	50	13544
Vantaan Energia Oy	1151	38	0	2001	7	0	3197

Small scale production units of district heating produced 125,498 GWh in 2007, of which 65,998 GWh was produced in Espoo and 59,5 GWh in Vantaa.

3.1 Helsinki

In 2007, the main district heating network line length of Helsinki was 1238 km. Figure 5 depicts the district heating network of Helsinki.

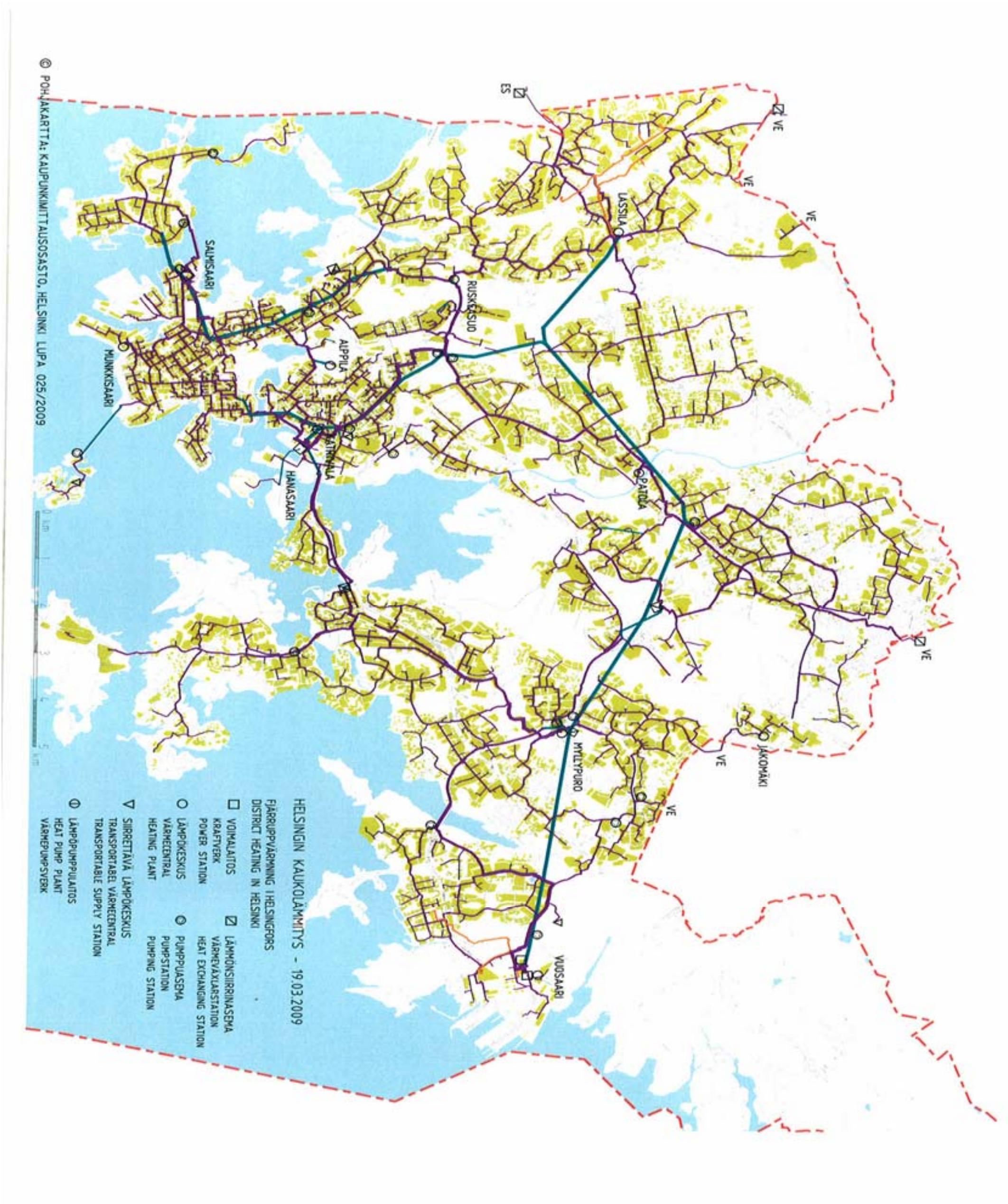

Figure 5. District heating network of Helsinki.

In Helsinki, 92.5 % of the inhabitants are living in district heated buildings and 85.7 % of the floor area is heated by district heating. In 2007, there was total of 6410 GWh thermal energy consumed in Helsinki district heating network and produced 6864 GWh in energy production units of Helsingin Energia. District heating network of Helsinki is connected to district heating networks of Vantaa and Espoo (Adato Energia Oy 2008, Helsingin Energia 2008, Statistics if Finland 2008).

There is only one small scale district heating unit in Helsinki; Salmisaari backup steam station. Salmisaari's backup steam station uses heavy fuel oil as its main fuel and this is used mainly when the large energy production units are being run down in Salmisaari for maintenance and steam is needed to turn the turbines. Salmisaari backup steam station emissions are included into Salmisaari power plant emissions and that way included in the emission trading (Helsingin Energia 2008).

If they are not supplied by district heating, then buildings are mostly heated by electricity and light fuel oil. The floor area in these types of buildings is 75 % heated by electricity and light fuel oil in Helsinki. Figure 6 is shows how the floor area of the buildings is heated as divided by heat sources (Statistics of Finland 2008).

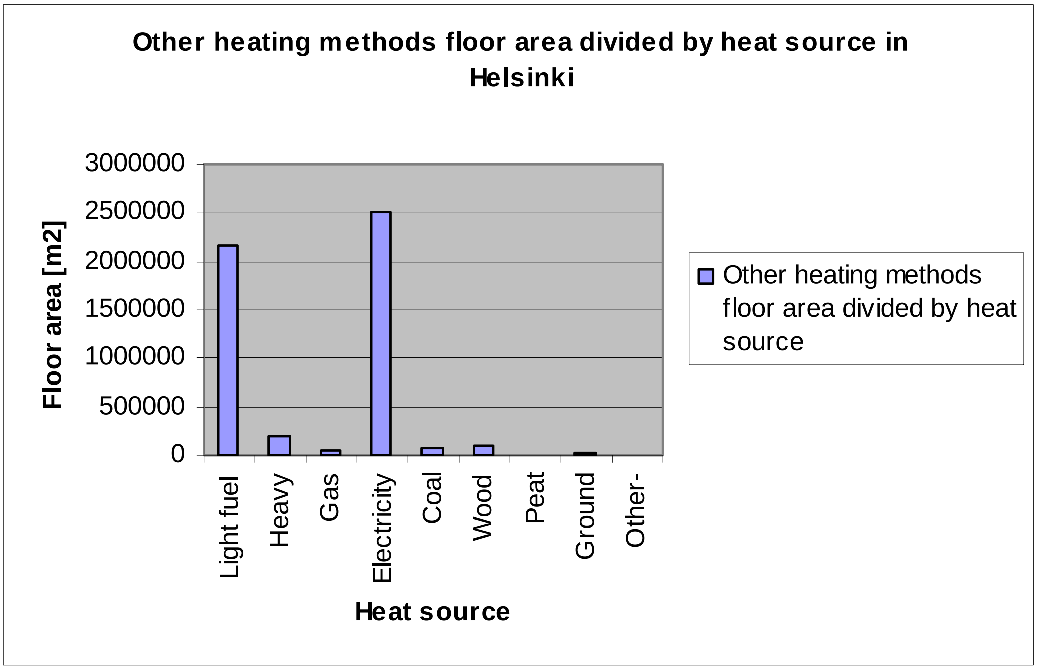

Figure 6. Floor area of buildings heated by other heat sources subdivided according to the heating method (Statistics of Finland 2008).

3.2 Vantaa

Vantaan Energia Oy had 439,2 km main district heating line installed in 2007 in Vantaa. District heating network of Vantaa is presented in figure 7.

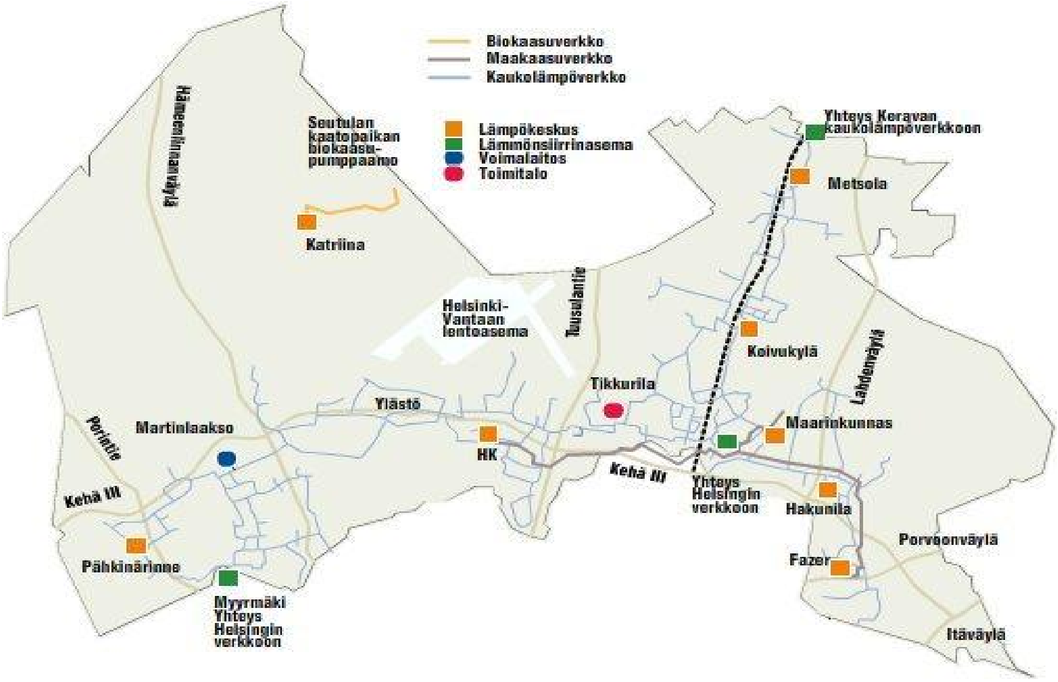

Figure 7. District heating network of Vantaa in 2007 (Vantaan Energia 2008).

In Vantaa 78,8 % of the inhabitants are living in buildings, which are heated by district heating and district heating buildings floor area fraction of the total floor area was 68,8 % in 2007. In the same year, a total of 1459 GWh thermal energy was consumed in district heating network of Vantaa and this produced 1716 GWh in energy production units of Vantaan Energia Oy. The district heating network of Vantaa is connected to the district heating networks of Helsinki and Kerava (Adato Energia Oy 2008, Statistics of Finland 2008)

In Vantaa there are five small scale district heating stations; Pähkinärinne, Metsola, Helsinki-Vantaa Airport and Katriina’s stations. Pähkinärinne and Metsola are backup stations and they did not produce thermal energy in year 2007. Helsinki-Vantaa Airport heat-only unit is a heavy fuel boiler station and used mainly to meet the thermal energy needs of the airport. Katriina's thermal heat-only units uses bio gas, which is produced in the Vantaa's landfill site and has its own district network. Since there is no large scale district heating unit in that network, Katriina's thermal energy production units are not included in the emission trading (Vantaan Energia 2008, Statistics of Finland 2008).

Vantaan Energia Oy owns also Fazer and HK-ruokatalo steam production units in Vantaa, of which Fazer steam production unit is connected to main district heating network by a condenser, but this is not the case for the HK-ruokatalo unit. These units produce steam for a factory to which they are connected (Vantaan Energia 2008).

Other used heating methods floor area in Vantaa by source of energy is shown in figure 8. As in Helsinki, the major methods to heat buildings area are electricity and light fuel oil (Statistics of Finland 2008).

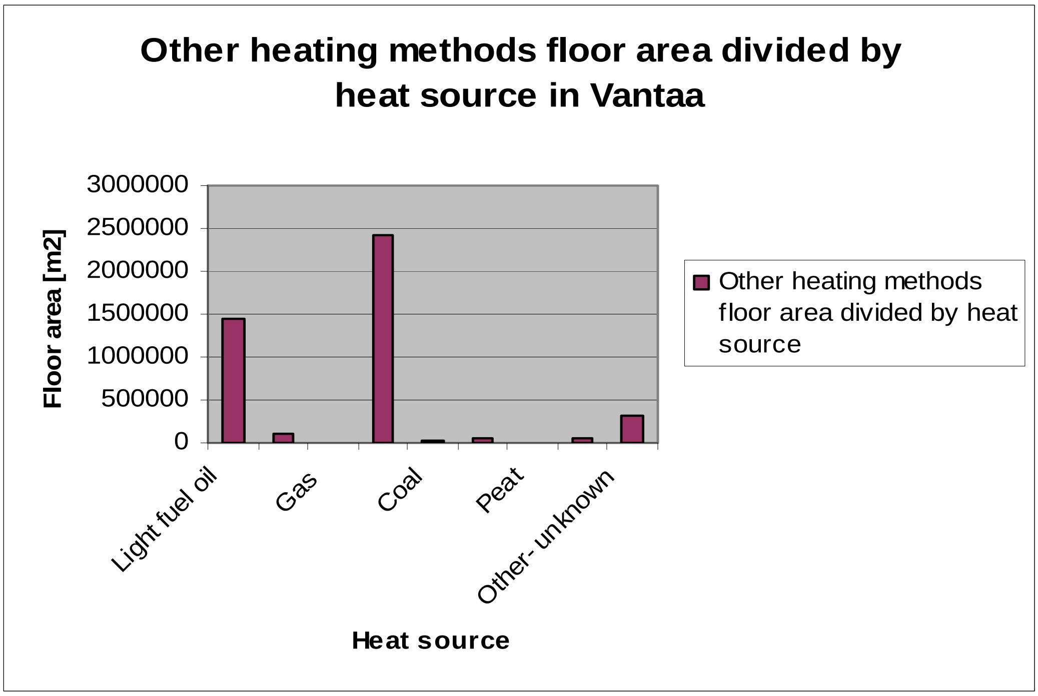

Figure 8. Other heating methods floor area subdivided according to the heat source (Statistics of Finland 2008)

3.3 Espoo

Fortum Heat and Power Oy, Espoo - Energy Company had 754 km district heating line installed in 2007. District heating network of Espoo is presented in figure 9.

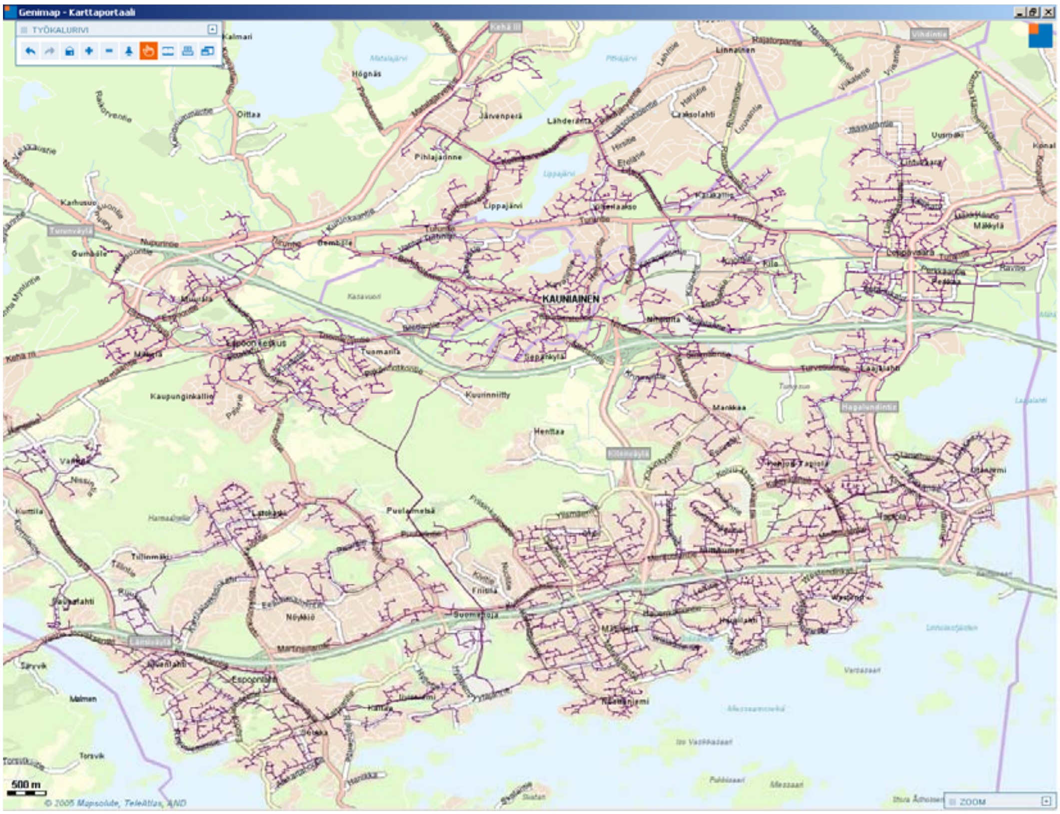

Figure 9. District heating network of Espoo.

About three quarters, 77 %, of the inhabitants of Espoo are living in buildings, which are heated by district heating and the buildings floor area fraction of is 67,6 % of the total. A total of 1809 GWh was consumed in district heating network of Espoo and 2098 GWh was produced in energy production units by Fortum Heat and Power, Espoo (Adato Energia Oy 2008, Statistics of Finland 2008).

In Espoo there are four small scale district heating units; Suomenoja 4, Juvanmalmi, Auroranportti and Kalajärvi. The main fuel used by Juvanmalmi, Auroranportti and Kalajärvi units is natural gas with the supplementary fuel being heavy fuel oil. The Kalajärvi unit has a separate district heating network and not included into the emission trading system.

District heating network of Espoo is connected to district heating networks of Kauniainen and Helsinki. Kauniainen does not have any energy production units so all istrict heating in Kauniainen is supplied from the district heating network of Espoo.

In Espoo thermal energy production for other heating is mostly from electricity and light fuel oil heating in Espoo. These heating methods subdivided according to source of thermal energy are presented in figure 10.

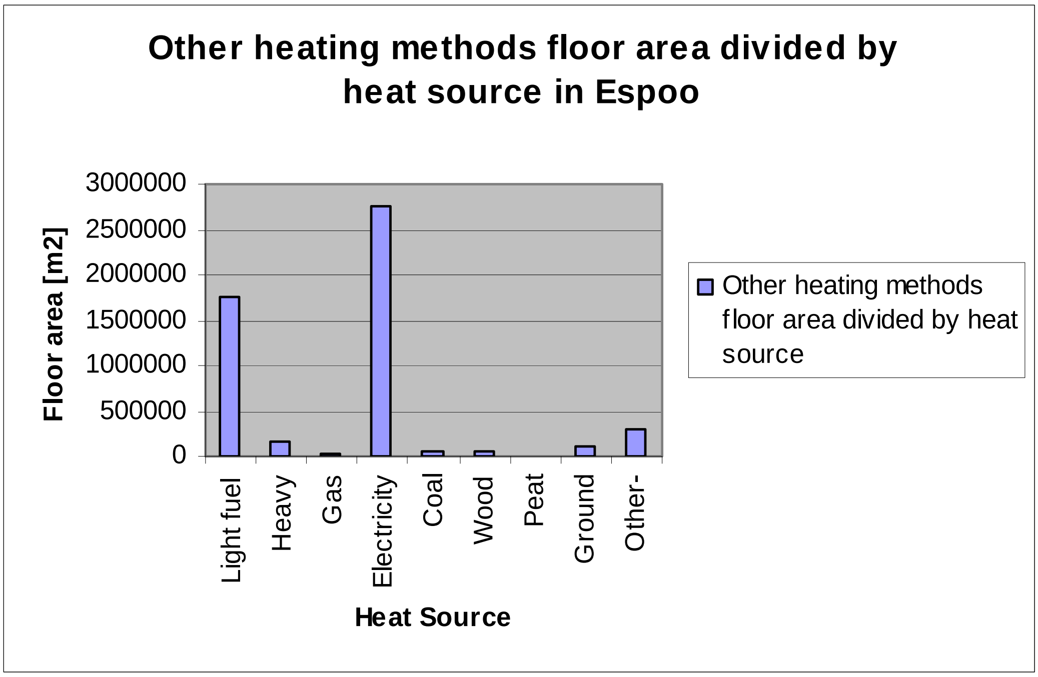

Figure 10. Floor area division of the other heating methods in Espoo (Statistics of Finland 2008)

3.4 Kauniainen

There is no district heating production in Kauniainen and there for thermal energy what is used in the district heating network is supplied from district heating network of Espoo. District heating accounts for 40,9 % of the total floor area and is available to 75,2 % of the inhabitants in Kauniainen.

The other heating methods in Kauniainen utilize thermal energy obtained mainly from light fuel oil and electricity. Heavy fuel oil heating accounts for a significant part of the total floor area, unlike the other parts of Helsinki Metropolitan area. The sources of energy used in Kauniainen are shown in figure 7.

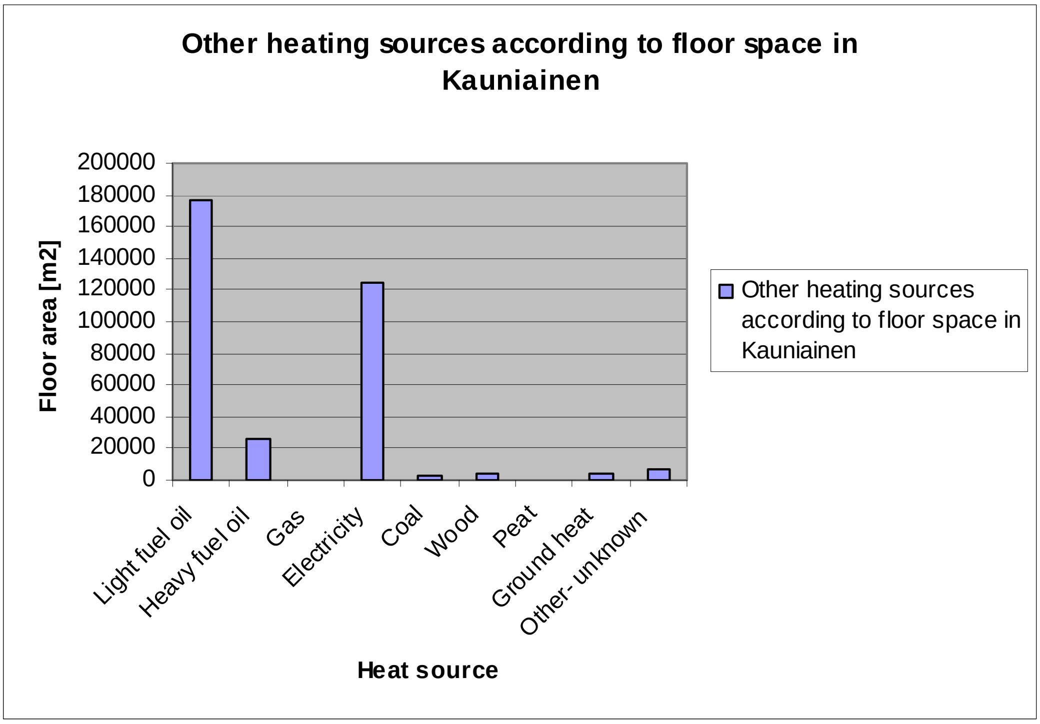

Figure 11. Other heating sources according to floor space in Kauniainen. (Statistics of Finland 2008)

4. FUTURE OF THE HEAT PRODUCTION IN THE AREA

In this study, the total need of thermal energy in a city is calculated from the equation, which is presented in the equation 3. As shown in table 1, the U-values regulations have become stricter and in 2010 regulations will tighten again by 30-40 %. Buildings also have been renovated, which makes evaluations for their U-values impossible without measurements or data about energy used in the actual buildings. This makes calculations of the demand for thermal energy demand more complicated for the buildings being heated by other means, because there is no detailed data of thermal energy consumed these buildings as there is for district heating buildings (Seppänen O., 2001).

4.1 Need for thermal energy in the cities

Thermal energy is needed in buildings to heat indoor air and for warm tap water, which is used mainly for cooking and washing. Each inhabitant is estimated to consume 155 dm^3 tap water in Helsinki Metropolitan area per a day with 40 % of total tap water being warm tap water (Seppänen O., 2001, Helsingin Vesi 2009). The thermal energy used to heat the tap water can be calculated by equation 2 and table 16 presents the calculation results for thermal energies, which are needed to heat tap water in each city. Estimates for inhabitants in the future are taken from the YTV report of future changes in Helsinki Metropolitan area. Tap water is estimated to be heated at 60 °C and cold water to be in 4 °C temperature (Seppänen O., 2001, YTV 2003).

Table 16. Thermal energy used to warm tap water (Helsingin Vesi 2009, YTV 2003).

	2007 [GWh]	**2013 [GWh]**	**2020 [GWh]**	**2025 [GWh]**	**2030 [GWh]**
Helsinki	229,74	238,03	245,33	250,54	255,76
Vantaa	77,80	85,05	92,01	96,98	101,96
Espoo	96,20	104,41	114,22	121,23	128,24
Kauniainen	3,44	3,76	3,88	4,04	4,16
TOTAL	407,18	431,24	455,44	472,80	490,12

The thermal energy needed to heat indoor air can be calculated by subtracting the thermal energy, used for warming tap water from the total need of thermal energy as shown in equation 3. This can be done for buildings using district heating in Finland and from data about all building. This way the U-values of district heating buildings can also be calculated. If one assumes that the overall thermal transfer per floor area in the buildings using other forms of heating is the same as in buildings heated by district heat supply in each city, the total need of thermal energy to heat indoor air can be calculated into the sum of from thermal energy in the district heating and other types of heating in use (Adato Energia 2008, statistics of Finland 2008). This is described by the equation 4.

$$
\begin{aligned}
Q^{2007}_{thermal,city} &= Q^{2007}_{thermal,districtheating} + Q^{2007}_{thermal,otherheating} \\
&= U^{2007}_{Buildings,districtheating} A^{2007}_{floor,districtheating} (T_{in} - T_{out}) + U^{2007}_{Buildings,otherheating} A^{2007}_{floor,otherheating} (T_{in} - T_{out}) \\
&= U^{2007}_{Buildings,districtheating} A^{2007}_{floor,districtheating} (T_{in} - T_{out}) + U^{2007}_{Buildings,districtheating} A^{2007}_{floor,othe\ heating} (T_{in} - T_{out}) \\
&= Q^{2007}_{thermal,city,districtheating} + Q^{2007}_{thermal,city,districtheating} * \left[(1 - \alpha^{2007}_{districtheating,city}) / \alpha^{2007}_{districtheating,city} \right],
\end{aligned} \tag{4}
$$

where $Q^{2007}_{thermal,city}$ = Total need of thermal energy to heat indoor air in a city,

$Q^{2007}_{thermal,districtheating}$ = Need of thermal energy to heat indoor air in district heating buildings in a city,

$Q^{2007}_{thermal,otherheating}$ = Need of thermal energy to heat indoor air in buildings with other types of heating methods in a city and

$\alpha^{2007}_{districtheating}$ = Floor area of district heating buildings floor area as a fraction of the total floor area in city.

The total need of thermal energy to heat the indoor air in future years in each city is presented in table 15 taking into account predicted increases in floor area. The floor area increase in each city is estimated to be same as stated in the Helsinki Metropolitan Council (YTV) – report (YTV 2003).

Table 15. Total need of thermal energy to heat up indoor air in Helsinki metropolitan area cities.

	2007 [GWh]	**2013 [GWh]**	**2020 [GWh]**	**2025 [GWh]**	**2030 [GWh]**
Helsinki	7 228	7 617	8 071	8 395	8 719
Vantaa	2 040	2 227	2 445	2 601	2 757
Espoo	2 565	2 857	3 197	3 440	3 683
Kauniainen	173	186	202	214	225
Total	12 006	12 887	13 916	14 650	15 384

The assumption that *U*-values for district and other used heating methods buildings are same is not really accurate, because district heating buildings are mainly apartment houses and buildings using other heating methods are mainly separate residential buildings. The *U*-values difference is hard to evaluate, because the wall and floor area ratio are different in different buildings and thus also the U-values are also different. In this study it is estimated that the *U*-values of those other buildings are the same as buildings heated by district heating.

If the floor area and inhabitant estimated increase is taken into account, the total need of thermal energy is presented in the figure 12 for future years. Total need of thermal energy for years 2013, 2020 and 2030 are estimated from interpolation of the curve of calculated need of thermal energy levels between situation in 2007 and 2025.

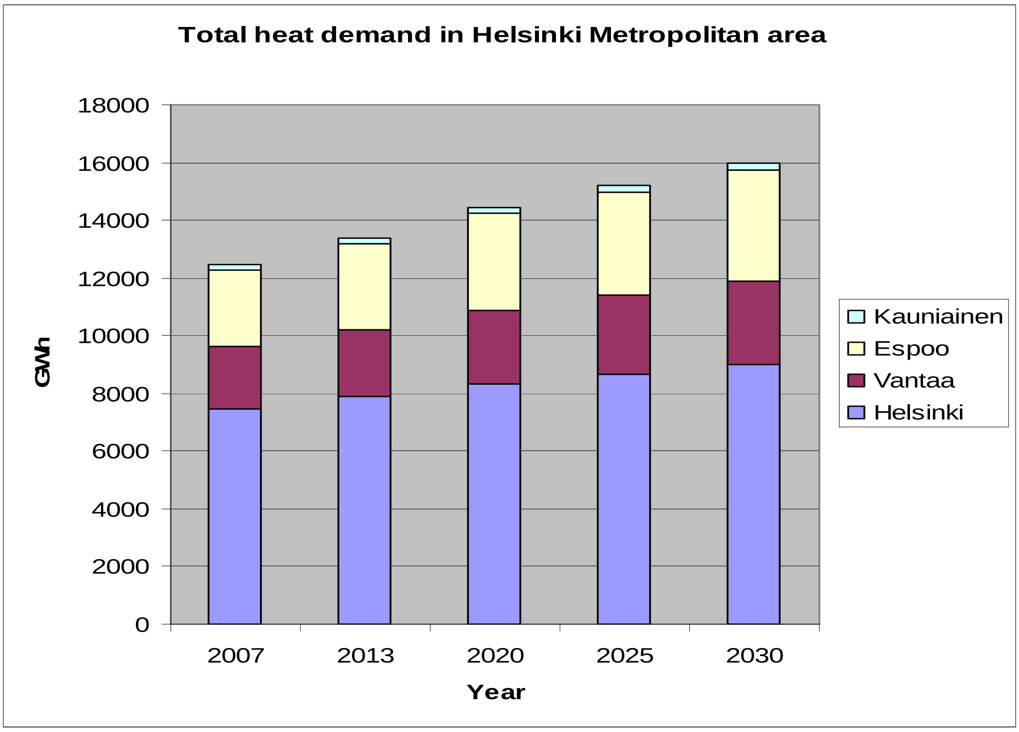

Figure 12. Total need of thermal energy estimations in Helsinki Metropolitan area, if only floor area and inhabitant increases are taken into account (Adato Energia 2008, Statistics of Finland 2008).

These calculations indicated that 1048 GWh thermal energy was consumed in those building heated in other ways in Helsinki. The city of Helsinki environmental centre has also calculated how much thermal energy was consumed in Helsinki in the year 2007 – this estimation is the combined total for individual property, industry and work machinery and amounted to 700 GWh (Environmental centre of Helsinki 2008).

The increase need of thermal energy between years 2007 and 2025 can be calculated from equation 5, if one estimates that the U-values of the new buildings and the average outdoor temperature will be the same as in 2007.

$$\begin{aligned}
\Delta Q_{thermal}^{2007-2025} &= \Delta Q_{thermal,Helsinki}^{2007-2025} + \Delta Q_{thermal,Espoo}^{2007-2025} + \Delta Q_{thermal,Vantaa}^{2007-2025} + \Delta Q_{thermal,Kauniainen}^{2007-2025} \\
&= (\Delta\alpha_{Helsinki}^{2007-2025} Q_{thermal,Helsinki}^{2007} + \Delta\alpha_{Espoo}^{2007-2025} Q_{thermal,Espoo}^{2007} \\
&+ \Delta\alpha_{Vantaa}^{2007-2025} Q_{thermal,Vatnaa}^{2007} + \Delta\alpha_{Kauniainen}^{2007-2025} Q_{thermal,Kauniainen}^{2007}) \\
&- (Q_{thermal,Helsinki}^{2007} + Q_{thermal,Espoo}^{2007} + Q_{thermal,Vantaa}^{2007} + Q_{thermal,Kauniainen}^{2007}),
\end{aligned} \tag{5}$$

where $\Delta Q_{thermal}^{2007-2025}$ = Change in total need for thermal energy in the Helsinki Metropolitan area between years 2007 and 2025,

$\Delta\alpha_{city}^{2007-2025}$ = Change in floor area in a city as compared to year 2007.

Need of thermal energy increase in Helsinki metropolitan area is then

$$\begin{aligned}
&\Delta Q_{thermal,Helsinki\,Metropolitan\,area}^{2007-2025} \\
&= (1{,}16 * 7458 GWh + 1{,}34 * 2661 GWh + 1{,}27 * 2118 GWh + 1{,}24 * 176 GWh) \\
&- (7458 + 2661 + 2118 + 176) \\
&\approx 2736 GWh.
\end{aligned}$$

It is natural that an increase in buildings floor area and population will affect head demand by increasing, but the need for thermal energy is affected also by other factors. Energy consumption habits, the total overall heat transfer coefficient of the building, outdoor and indoor temperatures have a major affect on the total need of thermal energy. The better overall heat transfer coefficient of the new buildings and global warming will have a reducing effect on the total need of thermal energy. In a report about district heating and cooling in the future in

Finland it was estimated that the total consumption of district heating will start to decline in Finland after the year 2020, because of global warming and improved energy efficiencies of buildings (Seppänen O. 2001, Vehviläinen et al. 2007).

4.1.1 Global warming

Global warming will affect also the Helsinki Metropolitan area and the way it will influence the need for thermal energy is calculated in this paragraph. The Finnish metrological institute has assessed that annual average temperature will rise 1 °C to year 2030. Thus in the year 2025, the average outdoor temperature is predicted to be 0,7826 °C higher than in year 2007 in Helsinki metropolitan area, if the current trend continue (Finnish metrological institute 2009).

The impact of global warming on total need of thermal energy can be calculated by using equation 1. If it is estimated that the affect of global warming would be stable throughout the year and the indoor temperature would be 17 °C, then the need for heating in the Helsinki metropolitan area warming would lower of in year 2025 by 7,58 % as shown in equation 6.

$$\begin{aligned}
\Delta Q_{thermal}^{2007-2025*} &= Q_{thermal}^{2007-2025} \frac{Q_{thermal}^{2025*}}{Q_{thermal}^{2007}} \\
&= Q_{thermal}^{2007-2025} \frac{U_{Buildings}^{2025} A_{floor}^{2025} (T_{in}^{2025} - T_{out}^{2025*})}{U_{Buildings}^{2007} A_{floor}^{2007} (T_{in}^{2007} - T_{out}^{2007})} \\
&= Q_{thermal}^{2007-2025} \frac{T_{in}^{2007} - T_{out}^{2025*}}{T_{in}^{2007} - T_{out}^{2007}} \\
&= Q_{thermal}^{2007-2025} \frac{17^{\circ}C - (6,71 + 0,24)^{\circ}C}{17^{\circ}C - 6,71^{\circ}C} \approx 0,954 * Q_{thermal}^{2007-2025} \quad ,
\end{aligned} \tag{6}$$

where $Q_{thermal}^{2025*}$ = Total need for thermal energy in year 2025 in Helsinki Metropolitan area, when affect of global warming is taken into account,

$Q_{thermal}^{2007}$ = Total need of thermal energy in year 2007 in Helsinki Metropolitan area.

$\Delta Q_{thermal}^{2007-2025}$ = Change in total need of thermal energy in the Helsinki Metropolitan area between years 2007 and 2025 and

$\Delta Q_{thermal}^{2007-2025*}$ = Change in total need of thermal energy in the Helsinki Metropolitan area between the years 2007 and 2025, when the effect of global warming is taken into account.

Thus the need of thermal energy would be 1534 GWh higher in 2025 than in 2007.

4.1.2 Buildings' energy efficiencies

The Finnish government is planning to tighten buildings energy efficiency regulations by 30-40 % in the year 2010. In the YTV's report, it is estimated that 5-6 % of the old building stock will be renewed to year 2025 (YTV 2003), which means that as those new buildings are more energy efficient, thus will save a maximum of 299 GWh thermal energy each year.

$$Q_{thermal,renew,\max}^{2025} = 6\% * 40\% * Q_{thermal}^{2007} = 0,06 * 0,40 * 12,460\, TWh \approx 299\, GWh,$$

where $Q_{thermal,renew,\max}^{2025}$ = Maximum savings from renewal of old building stock.

It is estimated that buildings which are built in 2007 or after would have 40 % better total overall heat transfer coefficient per floor area, than the old building stock. Taking this into account, the need of thermal energy would be 920 GWh higher than in 2007 in Helsinki Metropolitan area.

$$\Delta Q_{thermal}^{2007-2025} * (1-40\%) = 0,60 * 1534 GWh = 920\ GWh$$

If the heat saved by renewal the renew of old building stock is taken into account, then the need for a thermal energy increase would be 632 GWh, if estimated that 6 % of the old buildings stock would renewed.

4.1.3 Total need of thermal energy in Helsinki metropolitan area cities

Based on these calculations, the future need of thermal energy increase is shown in table 17.

Table 17. Total need of thermal energy in Helsinki metropolitan area, if the increase in floor area, global warming and building stock renewal are taken into account.

Total need of thermal energy					
	2007 [GWh]	**2013 [GWh]**	**2020 [GWh]**	**2025 [GWh]**	**2030 [GWh]**
Helsinki	7 457,69	7477,1572	7499,866	7516,087	7532,307949
Vantaa	2 118,15	2194,7317	2284,081	2347,903	2411,724001
Espoo	2 661,25	2806,9805	2977,005	3098,451	3219,897455
Kauniainen	176,13	180,4451	185,4779	189,0727	192,6675787
Total	12 413,21	12 659,31	12 946,43	13 110,82	13 356,60

The sensitivity analysis for total thermal energy requirements in Helsinki metropolitan can be valued by assuming that the U-values of the other used heating methods have ± 20 % margin of error. Calculations show that varying other used heating methods U-value ± 20 % will change the thermal energy demands in cities ± 4,26 %.

4.2 Model for heating in Helsinki metropolitan area

The model of energy production in Helsinki Metropolitan area is constructed by the Gabi 4,3 life cycle assessment program. The basic idea of a life cycle assessment is to model every flow and emission from raw material to end of the product. In this case, it is impossible to model every flow and emission, because there are such vast amounts of flows and emissions in energy production, but the main flows and emissions are modelled.

In the model, Helsinki Metropolitan area is divided into four areas by the cities; Espoo, Helsinki, Kauniainen and Vantaa. Each city has a process to define need of thermal energy in the city and how much each heating method produces energy, which are calculated based on district heating and floor area statistics and the calculations in chapter 3,1 (Statistics of Finland 2008).

The use of floor area statistics does introduce some unreliability into the calculation, because it is based on the building registry. Data in the building registry is not updated, if the change of heating method does not require building permission. This why estimations for the other heating methods fractions are better estimated by using Haaparanta et al 2003 report of small scale combustion in Helsinki Metropolitan area.

In the Haaparanta et al 2003 report, it is estimated that 44 % in Helsinki, 60 % in Espoo and 66 % in Vantaa of separate residential houses, which do not use wood as their main heating source, do use wood for supplementary thermal energy production. The main method to produce thermal energy in these residential buildings is a thermal energy reserving stove; in the Helsinki Metropolitan area about 90 % of thermal energy is produced by this type stove. Almost all the new residential houses are assessed to have a stove for burning wood. In the model calculations 153 850 GigaJoules (GJ) of thermal energy is produced in buildings, which use wood as main fuel, and in Haaparanta et al. 2003- report total thermal energy produced from wood is estimated to be 945 000 GJ in 2002. The total thermal energy produced from wood can estimated to be significantly higher than the floor area statistics show (Haaparanta et al. 2003). In this study, the total thermal energy production fraction from wood is estimated to be six times more then the statistics would indicate. This data from the estimation is made based on Haaparanta et al 2003- report.

The amount of district heating production in each city is taken from district heating statistics and the single district heating production unit values from energy company data; these values are reliable.

Large scale district heating units are not modelled individually in the same way as small scale district heating units. Emissions of large scale district heating units are calculated by using fuel information of district heating statistics and emission factors for district heating units are taken from Kivihiilitoimikunta 2004 and Karvosenoja M., 2008 – reports or calculated by using emission from the companies data themselves (Fortum Heat and Power 2008, Helsingin energia 2008, Vantaan energia 2008). The large scale district heating units are divided to six groups based on the fuel or heat source, which are natural gas, coal, heavy fuel oil, light fuel oil, biogas and geothermal heat.

A possible new nuclear plant is may be built in Loviisa. All of the nuclear plant parameters are taken from Fortum's application for permission to build the 6^{th} nuclear plant in Finland. This plant is estimated to start to produce energy by 2020 and to supply 1000 MW thermal energy to the district heating network of Helsinki. This would be more than enough to cover the total need of thermal energy in Helsinki and some of the needs of thermal energy in Vantaa and Espoo. This would dramatically change the energy production in the Helsinki metropolitan area and would lower the carbon dioxide emissions considerably, because the fossil fuels would be replaced by nuclear fuel. If the nuclear plant is connected to the district heating network of Helsinki, it would produce excess energy. In the model this excess thermal energy is estimated to be transferred then evenly through the district heating networks of Vantaa and Espoo. Thus, these kinds of thermal energy flows between district heating networks are also included in the model (Fortum Heat and Power Oy 2008b).

Figure 11 depicts the model in the 2007 situation. The flows in the figure are thermal energies. Sub-plans for the other heating methods in use and small scale district heating unit processes are to used make the model structure simpler.

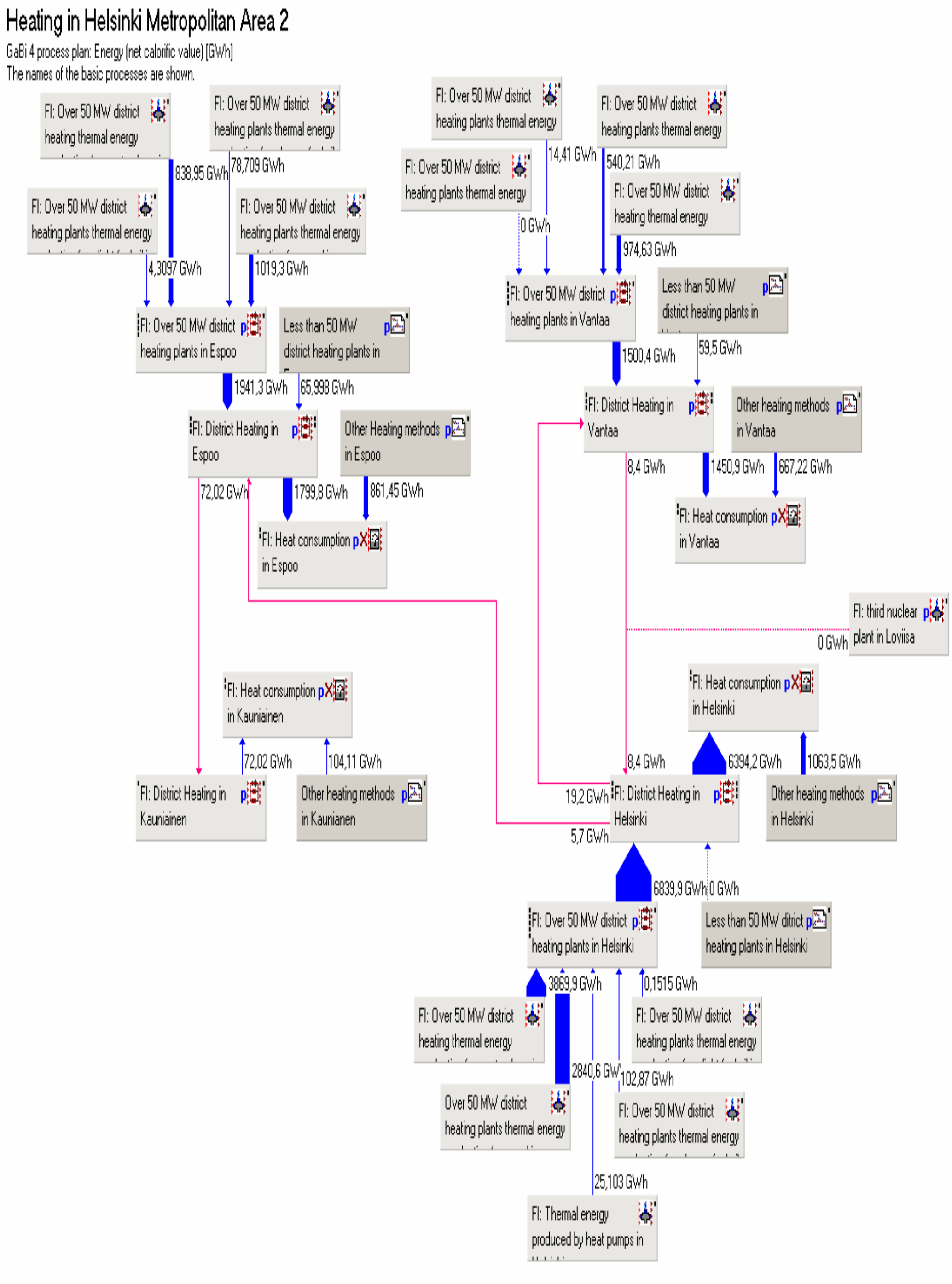

Figure 11. Simplified figure of the Gabi-model for the year 2007.

As shown in the figure 11, most of the thermal energy in cities is produced by district heating, except in Kauniainen. District heating is produced mainly from coal and natural gas and the amount of thermal energy produced in small scale district heating units is a very small fraction of the total.

Figure 12 describes the division of other used heating methods.

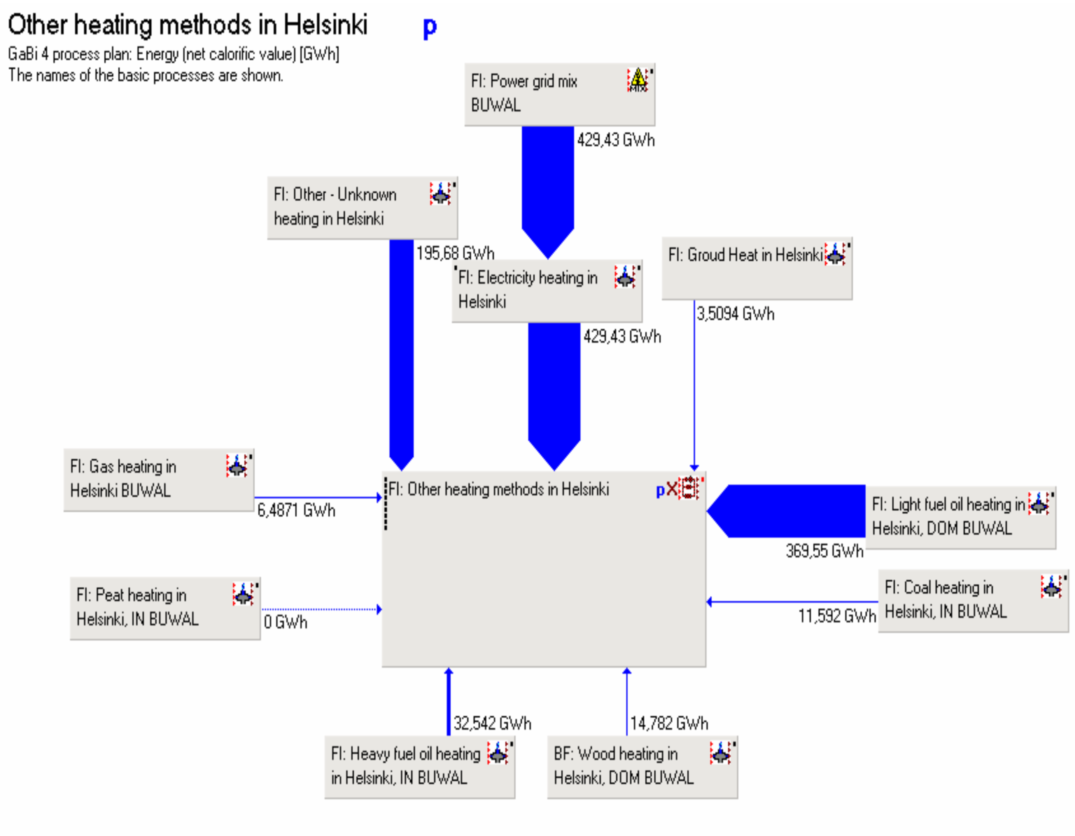

Figure 12. Other used heating methods in the sub-plan of Helsinki.

The division of other used heating methods in use is based on floor area statistics, where these other heating methods are divided into nine groups; coal, geothermal, electricity, heavy fuel oil, light fuel oil, natural gas, peat, wood and other-unknown heating.

The sub-plan of small scale district heating units in Vantaa is shown in figure 13.

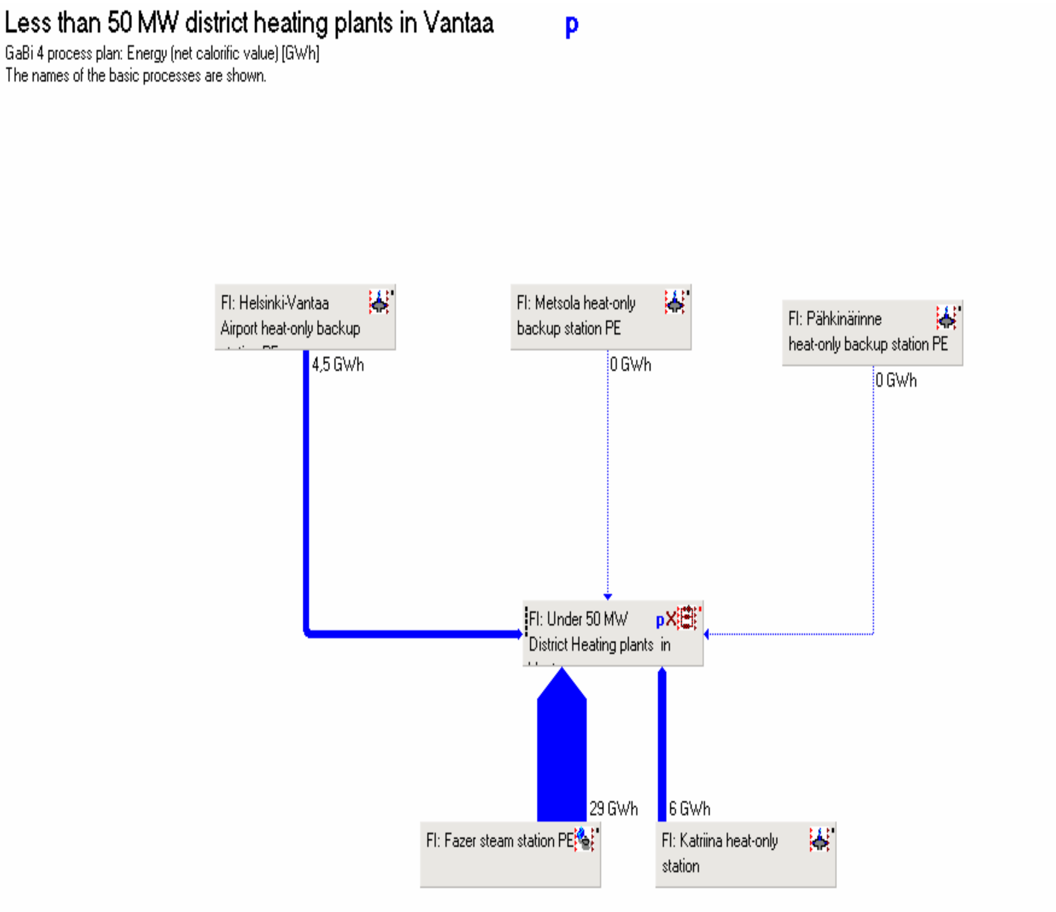

Figure 13. Sub-plan for small scale district heating units in Vantaa.

Small scale district heating units are individually modelled. Produced thermal energy and emissions are assessed individually for each small scale district heating unit, based on data from the energy production companies (Fortum Heat and Power 2008, Helsingin energia 2008, Vantaan energia 2008).

The assessment of district heating and cooling future in Finland has evaluated future consumption of district heating and cooling up to year 2050 and has estimated which fuels will be used to produce the needed district heating. According to that assessment the demand for district heating is estimated to start to decline after the year 2020 in Finland and the future distribution of used fuels is presented in figure 14 (Vehviläinen et al. 2007).

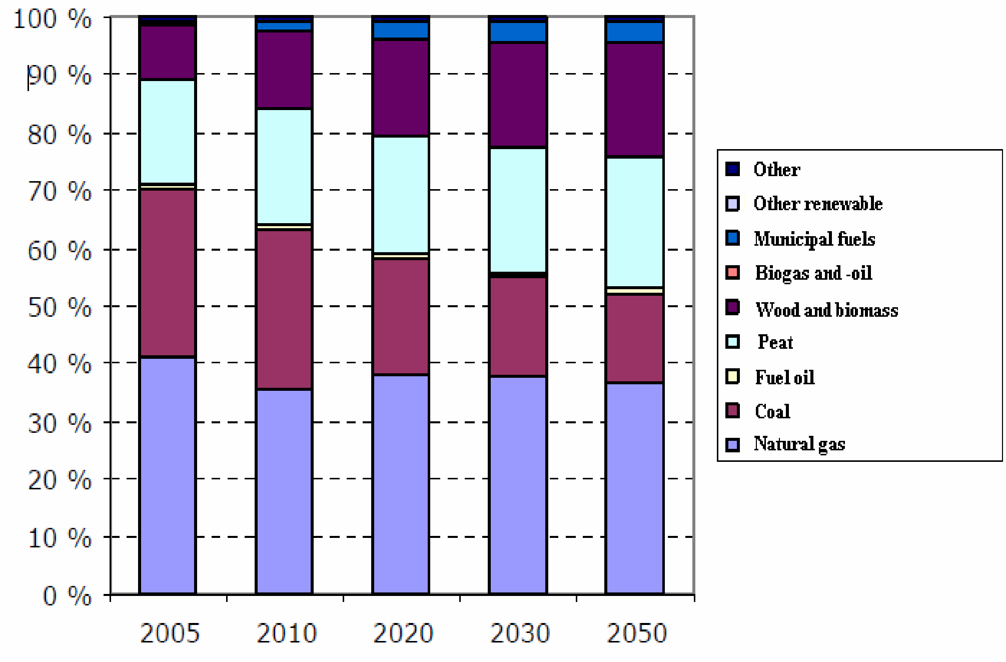

Figure 14. Distribution of used fuels in district heating units now and in the future (Vehviläinen et al. 2007).

The decrease of district heating consumption probably will not occur in Helsinki Metropolitan area as the calculations reveal in chapter 3.1, but the increase of district heating consumption can be expected be lower than in the past.

Helsinki Metropolitan Council estimates in the future that emissions per inhabitant will remain more or less at the same level as in 2007 (Aarnio et al. 2008). The fraction of heating method other than district heating with respect to the total floor area is estimated to be same as in 2007 in this study, because there are no studies or calculations about future changes for other used heating methods.

With respect to large scale district heating unit production, YTV estimates that major changes area will not happen until the year 2016 in Helsinki metropolitan, with only minor changes on the fuel side to less carbon dioxide emissions affecting fuels. Emission trading and clean air for Europe-program will bring pressure towards lower emissions in energy production (Aarnio at all 2008).

Changes occurring in thermal energy production in large scale district heating units are not assessed in this study, because this is not within the boundaries of this study. The distribution of used fuels and structure of large scale district heating units are estimated to be same as in 2007.

The model calculates the produced thermal energy for each heating method and district heating unit. When the produced energy is known, then the emissions can be calculated by using emission factors and efficiencies of different energy production methods. The district heating units emissions are calculated by using emission factors, which are presented in table 15, and district heating of Finland statistics, where is liste according to fuel use by the district heating companies. The estimates for the other heating methods in use are from Haaparanta et al (2003), where efficiencies of other heating methods are calculated by using statistics of produced energy in Finland 2002. Those calculations are presented in table 18.

Table 18. Efficiencies of other heating methods in use (Haaparanta et al. 2003, Statistics of Finland 2001)

	Consumption of energy [TJ]	**Beneficial energy [GWh]**	**Fraction [%]**	**Efficiency [%]**
Wood	41400	6325	13	55
Peat	510	85	0,2	60
Coal	90	15	0,03	60
Heavy fuel oil	3330	768	1,6	83
Light fuel oil	43100	9338	19	78
Natural gas	2020	505	1	90

The emission factors, which are used in the model, are presented in table 19.

Table 19. Used emission factors in the model (Kivihiilitoimikunta 2004, Karvosenoja 2008).

	Natural gas	Coal	Heavy fuel oil	Light fuel oil	Wood	Peat
Carbon dioxide [t/MWhfue]	0,20	0,34	0,28	0,27	0,41	0,38
PM2,5-factor for large scale district heating plants [kg/MWhthermal]	0,00	0,01	0,11	0,00	0,01	0,01
PM2,5-factor for small scale district heating plants [kg/MWhthermal]	0,00	0,11	0,11	0,00	0,11	0,11
PM2,5-factor for other used heating methods [kg/MWhthermal]	-	-	-	0,00	2,52	-

The following paragraph describes the results for calculations for different scenarios.

4.3 Scenarios

The calculations in chapter 3.1 and in the YTV 2003-report are used for future estimations. The district heating fraction of total floor area future development in a city has resulted in three scenarios described in this study. In the base scenario, floor area of district heating building is estimated to remain at the 2007 level. In scenario 1 floor area of district heating buildings is estimated to remain the same as the fraction of total floor area in 2007. In scenario 2, the floor area of district heating buildings fraction of total floor area is estimated to increase at the same rate as showm in figure 15 (Vehviläinen et al. 2007).

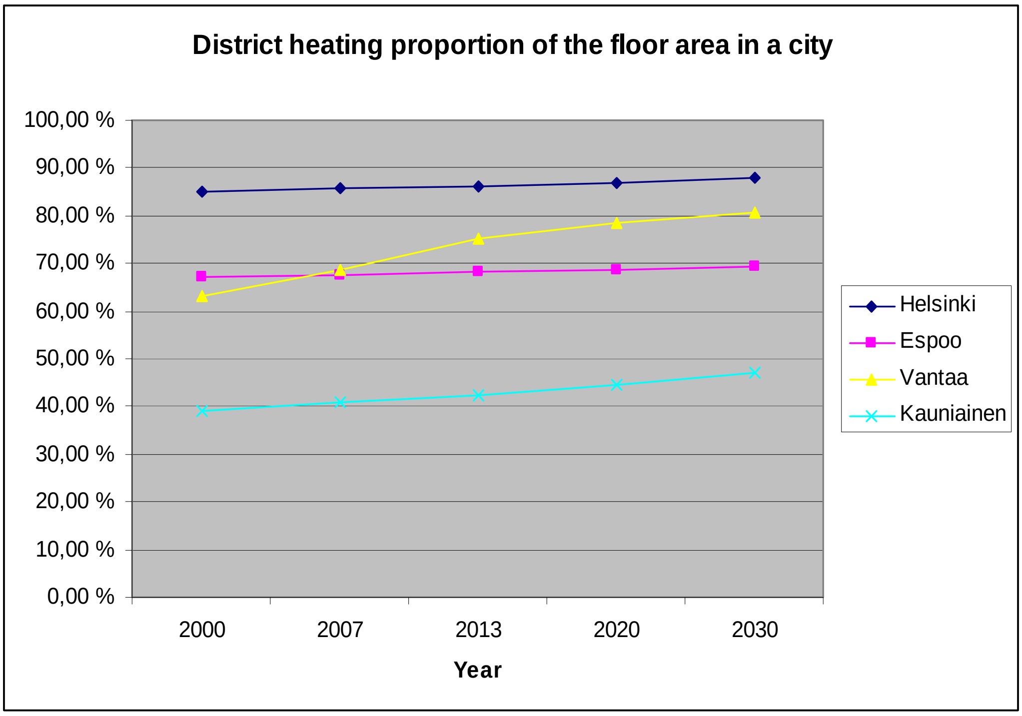

Figure 15. District heating building floor area fraction of the floor area in the future, if estimated that the increase would be as has been the case between the years 2000 and 2007 (Statistics of Finland 2000, Statistics of Finland 2008, City of Vantaa 2008).

4.4 Emissions

By allocating the need for thermal energy in each city; the model can calculate the emissions for the years 2007, 2013, 2020 and 2030. The model calculates for the emissions the situation, where it is estimated that the number of buildings, which are heated by district heating, will not increase from 2007 situation. The emissions are presented in table 20 for the base scenario.

Table 20. Emissions for base scenario.

	2007	2013	2020	2030
Total				
Carbon dioxide emissions [1000•t]	6083,9	6050,8	6027,1	6071,6
PM2,5-emissions [t]	676,7	806,4	944,6	1082,9
Small scale district heating units				
Carbon dioxide [1000•t]	23,7	25,1	26,3	27,2
PM2,5 [t]	0,2	0,2	0,2	0,3
Other heating methods in use				
Carbon dioxide [1000•t]	799,4	1013,8	1242,3	1484,6
PM2,5 [t]	500,5	638,6	785,3	930,5
Large scale district heating units				
Carbon dioxide emissions [1000•t]	5260,8	5011,9	4758,5	4559,8
PM2,5-emissions [t]	175,9	167,5	159,0	152,2

The results for emissions for base scenario with one difference, a nuclear plant would be built and connected to the district heating network of Helsinki, are presented in table 21. The nuclear plant is assessed to have 1000 MW thermal energy output, which means 7640 GWh thermal energy production each year.

Table 21. Emissions for the base scenario, if a new nuclear plant would be connected to district heating network of Helsinki.

	2020 nuclear	2030 nuclear
Total		
Carbon dioxide emissions [1000•t]	1461,1	1607,9
PM2,5-emissions [t]	794,8	935,7
Small scale district heating units		
Carbon dioxide [1000•t]	26,3	27,2
PM2,5 [t]	0,2	0,3
Other used heating methods		
Carbon dioxide [1000•t]	1242,3	1484,6
PM2,5 [t]	785,3	930,5
Large scale district heating units		
Carbon dioxide emissions [1000•t]	192,5	96,1
PM2,5-emissions [t]	9,3	4,9

Emissions for scenario 1 are presented in table 22.

Table 22. Emissions for scenario 1.

	2007	2013	2020	2030	2020 nuclear	2030 nuclear
Total						
Carbon dioxide emissions [1000•t]	6083,9	6193,7	6320,1	6502,2	1659,7	1841,7
PM2,5-emissions [t]	676,7	693,1	712,3	739,7	561,2	588,7
Small scale district heating units						
Carbon dioxide [1000•t]	23,7	25,1	26,3	27,2	26,3	27,2
PM2,5 [t]	0,2	0,2	0,2	0,3	0,2	0,3
Other used heating methods						
Carbon dioxide [1000•t]	799,4	611,2	844,3	881,8	865,3	881,8
PM2,5 [t]	500,5	409,8	525,0	545,3	535,3	545,3
Large scale district heating units						
Carbon dioxide emissions [1000•t]	5260,8	5557,5	5449,5	5593,2	768,0	932,7
PM2,5-emissions [t]	175,9	283,1	187,0	194,1	25,6	43,1

Emissions for scenario 2 are presented in table 23.

Table 23. Emissions for scenario 2.

	2007	2013	2020	2030	2020 nuclear	2030 nuclear
Total						
Carbon dioxide emissions [1000•t]	6083,9	6239,9	6411,1	6661,5	1750,4	2000,6
PM2,5-emissions [t]	676,7	662,2	650,9	631,8	499,9	481,0
Small scale district heating units						
Carbon dioxide [1000•t]	23,7	25,1	26,3	27,2	26,3	27,2
PM2,5 [t]	0,2	0,2	0,2	0,3	0,2	0,3
Other used heating methods						
Carbon dioxide [1000•t]	799,4	762,3	731,7	681,4	731,7	681,4
PM2,5 [t]	500,5	479,7	461,5	432,2	461,5	432,2
Large scale district heating units						
Carbon dioxide emissions [1000•t]	5260,8	5452,6	5653,1	5952,9	992,4	1292,0
PM2,5-emissions [t]	175,9	182,3	189,1	199,3	38,2	48,5

As shown in tables 20, 21, 22 and 23, the main emission of carbon dioxide are formed in large scale units of district heating and fine particle emission by other heating methods in use. Emissions from small scale units of district heating are less than 1 % of the total emissions if the nuclear plant is not connected and about 1,5 % if it is connected.

4.5 Costs

The model calculations shows that, if the production of district heating out of the total of the produced thermal energy is increased, total carbon dioxide emissions of energy production would increase but total fine particle emissions due to energy production decrease. It is notable that large scale units of district heating changes are not assessed in this study and in this model. It is the burning of coal use in production of district heating which is responsible for the increase in carbon dioxide emissions. Differences between the base scenario and the scenarios are presented in table 24.

Table 24. Emission differences between the base scenario and the scenarios.

	Difference between the base scenario and scenario 1		Difference between the base scenario and scenario 2	
	Carbon dioxide emissions of district heating [1000•t]	PM2,5-emissions of energy production in Helsinki Metropolitan area [t]	Carbon dioxide emissions of district heating [1000•t]	PM2,5-emissions of energy production in Helsinki Metropolitan area [t]
2013	333	-113	441	-144
2020	682	-232	895	-294
2030	1021	-343	1393	-451
2020 nuclear	588	-234	800	-295
2030 nuclear	824	-347	1196	-455

If it is estimated that the emission right price for one carbon dioxide ton would be 23 €, then total emission trading costs of district heating network expansion are presented in figures 15 and 16 for both scenarios.

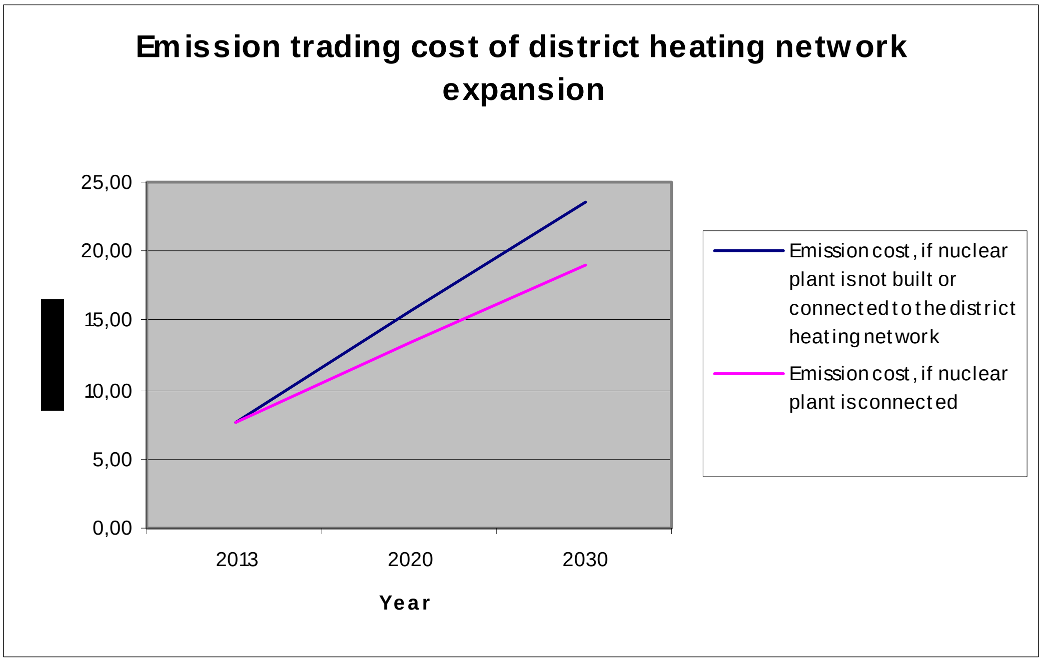

Figure 16. Emission trading cost of district heating network expansion for scenario 1.

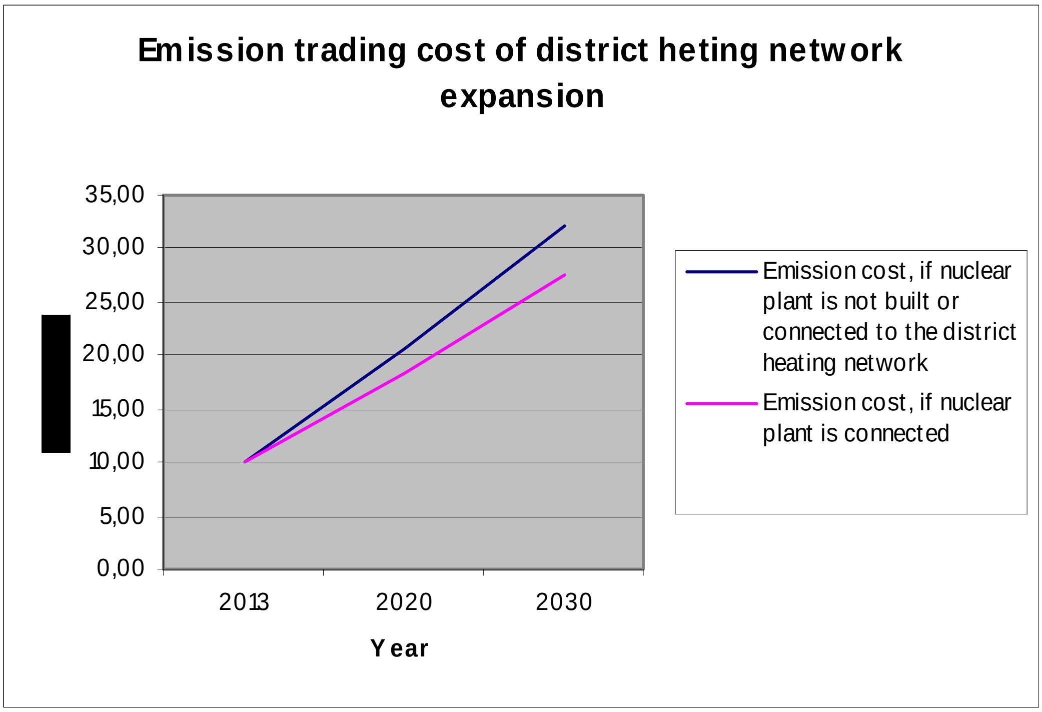

Figure 17. Emission trading cost of district heating network expansion for scenario 2.

The reduction cost attributable to fine particle emissions by extending district heating network can be assessed to be the emission trading cost, caused by higher carbon dioxide emissions in district heating energy production units, and the extension building cost of district heating network.

It is hard to calculate exately how much new district heating network line will be needed for these scenarios. In this study it is estimated that district heating network main line per floor area in a city is a static factor. Then new it is about 665,6 km of new district heating mainline will have to be built in scenario 1 and 890,9 km in scenario 2. In the Planora Oy 2009 – report there is a calculation that construction of 7360 meters district heating network line would cost 1 606 076 €, which is 218 000 €/km.

In addition to main district heating network line building cost, consumer has to pay the cost of connection of their own building to the district heating network. The construction cost from the main line to customer is funded by the consumer and taken into account in the price of thermal energy (Suorakanava Oy 2008). These consumers building cost are presented in table 25.

Table 25. Customer connection cost (Energiateollisuus 2009b).

	Connection cost				
Energy company	**[1000 €] separate residential house**	**[1000 €] row house**	**[1000 €] small apartment house**	**[1000 €] apartment house**	**[1000 €] large apartment house**
Fortum Power and Heat Oy, Espoo	3,07	7,47	15,10	26,55	53,93
Helsingin Energia	4,70	6,89	9,53	14,36	21,81
Vantaan Energia Oy	3,95	5,62	13,77	21,70	46,86
Arithmetical mean value	3,91	6,66	12,80	20,87	40,87

In the YTV-report Lainesvuo et al. 2001 have estimated that by the year 2020, the number of small residential building will increase by 60 % and residential apartment buildings by 50 % compared to the situation in the year 2000. This would translate into 26 389 new small residential buildings and 5484 new apparent buildings compared to the year 2007. If it is estimated that the fraction of district heating of these buildings will be the same as shown in figure 15 shows, then there would be 32032 new district heated small residential buildings and 6857 new apparent buildings in the year 2025. If it is estimated that these apparent buildings connection cost would be 20 870 € / apartment building, then consumer connection cost would be about 169 M€ in scenario 1 and 176,5 M€ in scenario 2 up to the year 2025 (Lainesvuo et al. 2001).

Total costs, which are affected by the district heating network extension, are presented in table 26. These can be assessed to be the reduction cost of fine particle emissions due to the extension of the district heating network.

Table 26. Fine particle reduction cost for district heting network extension.

	Base Scenario	Scenario 1-Base Scenario	Scenario 2	Base Scenario - Scenario 1 nucklear	Base Scenario - Scenario 2 nucklear
Intrest rate [%]	5,0	5,0	5,0	5,0	5,0
Annualized percentage rate [%]	13,0	13,0	13,0	13,0	13,0
Price of emission right [€/tCO2]	23,0	23,0	23,0	23,0	23,0
Building cost [M€]	0,0	468,6	531,6	468,6	531,6
Reduction of total fine particle emission [t]	23,7	343,2	451,1	494,2	601,9
Investment cost [M€/a]	0,0	60,7	68,8	60,7	68,8
Increase in emission trading costs [M€]	0,0	23,5	23,5	13,5	19,0
Fine particle reduction cost [€/kgPM2,5]	0,0	68,4	52,1	27,4	31,5

As table 26 show, the fine particle reduction cost by extending the district heating network would be 27 - 68 €/kg$_{PM2,5}$. Traditional reduction system cost for stationary combustion processes are assessed in the Karvosenoja 2008 report, which are 0,42 – 15 €/kg$_{PM2,5}$ for domestic wood combustion and for industrial and power plants 0,017 - 13 €/kg$_{PM2,5}$.

Increasing the proportion of houses using district heating fraction would be an effective way to decrease the fine particle emissions, but based on these figures it would not be the most cost effective way.

4.5.1 New nuclear plant cost comparison

In next paragraphs there is a comparison of the cost associated with different district heating production methods. Investment costs of power and heat plants have increased in the last years. Increase can be explained by increased material cost, metals and components price and the unbalanced demand and supply in power plant markets. Fuel prices are also been increasing in recent years. The overall cost increase will increase maintenance costs (Tarjanne et al. 2008).

In the calculations use January 2008 prices. The investment costs do not include value added tax but they do include building phase intrests and all the owner costs. The investment cost of power plant is based on the turnkey-principle supplied of a power plants price, when the commercial use starts. It is estimated that the building time for a nuclear will take six years and shorter times for the others plants. The efficiency of whole year for the each power plant is described as the yearly efficiency, which is the mean value of efficiencies. Government support for different energy production plants is not taken into account (Tarjanne et al. 2008).

The power output from the nuclear plant is 1500-1800 MW depending on the plant type. The power output of heat and power producing nuclear plants is 800-1500 MW and the heat output 1000 MW. In these calculations is assumed a nuclear plant with power output 1500 MW or a plant, which has a power output of electricity 800 MW and heat 1000 MW. The investment and Intrests of building phase for a nuclear plant is 4,125 milliard euros (2750 €/kW). Connecting the nuclear plant to the Helsinki metropolitan areas district heating network is estimated to cost 10 M€/km and modifications to the nuclear plant 500 M€. The district heating pipe would be 67 kilometres long, so the connection would cost roughly 1170 M€ more than if the plant only produced electricity (Tarjanne et al. 2008, Henriksson A., 2007).

The costs of closing down the nuclear plant and uclear fuel treatment and handling costs are included to the nuclear plants maintenance cost as a nuclear waste fee. Their proportion is about one fourth of the total maintenance costs. The efficiency of nuclear plants is estimated to be 37 %, if it produces only electricity and 80 %, if it produces heat and electricity (Tarjanne et al. 2008).

Currently wood is only used in combined heat and power plants as a fuel. Woodchip is the cheapest fuel of wood based fuels and it is a most suitable fuel for mixed combustion with shredded peat. There no exclusive electricity producing power plants in Finland today, because the costs of producing only for produced power would be higher than the market price. Therefore there are no optimised power plant types in Finland. The types of plants are small CHP-plants, with power output at a maximum of 30 MW. Due to these considerations, the investment costs of these exclusive power producing plant would be high, over 3000 €/kW and efficiency only 33 %. The price could be expected to decline when demand increases. In this study, for plant investment for building a 30 MW wood using heat plant is estimated to be 81 million euros (2700 €/kW) and its efficiency 80 % (Tarjanne et al. 2008).

The investment costs for coal CHP-plants are estimated to be 650 M€ and their efficiency 80 % (Tarjanne et al. 2008).

Fuel prices have increased rapidly in recent years. The changes in the oil price have been mirrored in the natural gas price. The nuclear fuel price is a combination of costs involved in ore refining. In the calculations the following fuel prices are used: nuclear fuel 1,85 €/MWh, Coal 6 €/MWh and woodchip 13,4 €/MWh (Pöyry energy oy, 2008). It is worth noticing that the nuclear fuel price is only a fraction of other fuels prices and the price of natural gas price is considerably higher than coal, woodchip or peat prices (Tarjanne et al. 2008).

Emission trading will affect the costs of power plant using coal, but not nuclear or wood using power plant costs. Stock markets list the prices for emission rights up to the year 2012. These calculations use a forward price of 23 €/ton$_{CO2}$. the European commission study use a price of nearly 60 €/ton$_{CO2}$ for emission trading phase three. In this study production costs are calculated also for situations where the emission rights price is zero or alternatively 60 €/ton$_{CO2}$ (Tarjanne et al. 2008).

Nuclear plants in Finland have an average annual usage of 8000 hours, and so they can be estimated to have a utilization rate of plants 91,3 % and this figure is used for the other plants as well. In reality, the utilization rate for coal and wood burning plant would be lower, but for the sake of comparison the same utilization rate is used in calculations (Tarjanne et al. 2008).

A plant's commercial lifetime refers to the time which is taken until the investment pays itself back. Technical lifetimes for plants are usually longer than this. The technical lifetime value of nuclear plants is usually estimated as 60 years and their commercial lifetime as 40 years. In the calculations, nuclear plants maintenance investments are included in nuclear plants maintenance costs. For the other plant types commercial lifetime is 25 years and they do not have maintenance investments (Tarjanne et al. 2008).

The market price of power affects the profit gained on power plant investments. Emission caps and emission right prices have clear a impact on the market prices development i.e. they increase the price. It is estimated that the forward price for power will be 23 €/MWh in 2013 and around the year 2020 it may have risen to 60 - 70 €/MWh. The starting values used in the cost calculations are listed in table 27 (Tarjanne et al. 2008).

Table 27. Starting values of cost calculations for different energy production plants.

	Nuclear	Nuclear CHP	Wood	Coal CHP
Power output [MW]	1500,0	800,0	0,0	150,0
Heat output [MW]	0,0	1000,0	30,0	300,0
Efficiency [%]	37,0	80,0	80,0	80,0
Investment cost [M€]	4125,0	5295,0	81,0	650,0
specific investment cost [€/kW]	2750,0	2941,7	2700,0	1444,4
Price of fuel [€/MWh]	1,9	1,9	13,4	6,0
Fuel cost of power/heat production [€/MWh$_{power/heat}$]	5,0	2,3	16,8	7,5
Maintenance costs, when 8000 h /a [€/MWh]	10,0	10,0	9,0	8,0
Portion of dynamic costs [%]	50,0	50,0	40,0	70,0
Commercial lifetime [a]	40,0	40,0	25,0	25,0
Intrest rate [%]	5,0	5,0	5,0	5,0
Annualized percentage rate[%]	5,8	5,8	7,1	7,1
Price of emission right [€/tCO2]	23,0	23,0	23,0	23,0
Annual use [h/a]	8000,0	8000,0	8000,0	8000,0
Utilization rate [%]	91,3	91,3	91,3	91,3
Annual payment [M€/a]	240,5	308,7	5,8	46,2

Costs for each fuel are presented in figure 17 for different emission right prices.

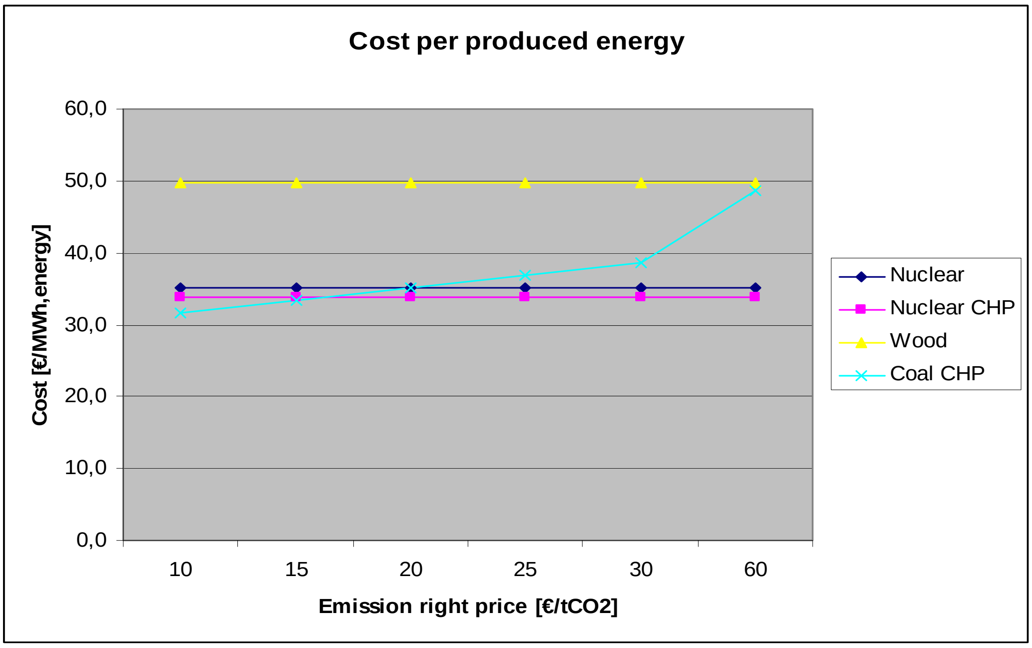

Figure 18.. Cost per produced energy for each fuel in different emission right prices.

Figure 18 shows that energy produced in coal plant is cheapest when the emission rights price is less 17 €/t_{CO2}. In these calculations national subsidies for energy production from wood are not taken into account.

4.6 Sensitivity analysis

Sensitivity analyses for carbon dioxide and fine particle emissions of the model are made parameters by giving the parameters margins of error. The margin of error for the thermal energy need in cities can be estimated to be ± 4,26 %. The statistics used in the calculations are based on building registry, which is not updated, if the change does not require building permission. Other used heating methods margins of errors are estimated to be ± 5 %, except for wood usage ± 10 %, because wood is used as secondary heating method in many buildings. The margin of errors for district heating units is estimated to be ± 2 %. The results of the sensitivity analysis are presented in figures 18 and 19.

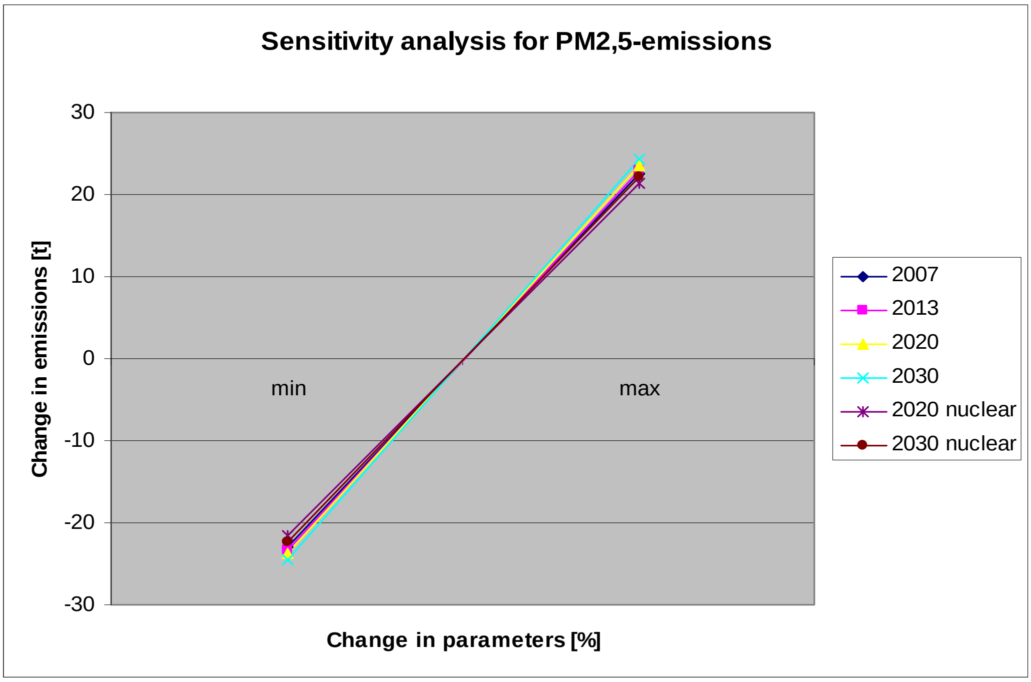

Figure 19. Sensitivity analysis for $PM_{2,5}$-emissions.

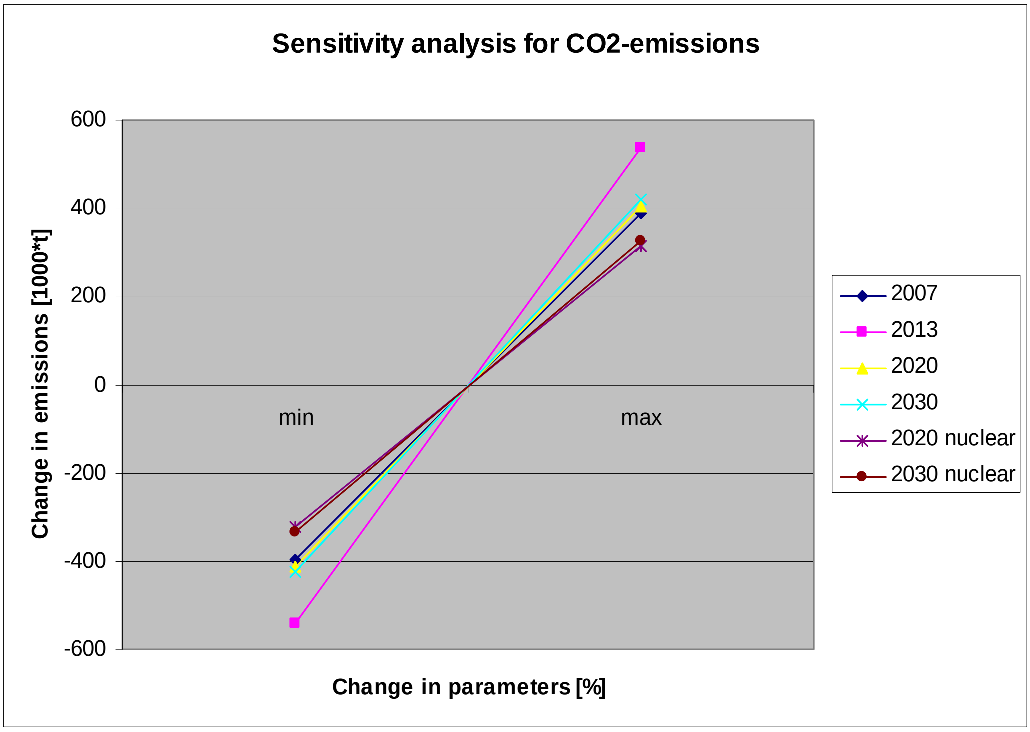

Figure 20. Sensitivity analysis for CO_2-emissions.

Mean margin of error for PM2,5-emissions ±10,26 % and for carbon dioxide emissions ± 8,34 %.

In this study it is estimated other heating methods than district heating fractions are as they were in the year 2007. In the future it is not curtain that this will happen; in fact it is more likely that the fractions will change depending on the fuel prices. By sensitivity analyse can be the heating methods changes effect on the carbon dioxide emissions estimated. Table 28 shows how the different heating methods changes would affect the total carbon dioxide emissions in the Helsinki Metropolitan area, if their use changes ± 5 % in the cities while the other heating methods compensate the change by decreasing or increasing accordingly.

Table 28. Sensitivity analysis for the overall emissions and changes in the heating methods.

PM2,5						
	2007	**2013**	**2020**	**2030**	**2020 nuclear**	**2030 nuclear**
Coal	0,02%	0,02%	0,02%	0,02%	0,05%	0,05%
Electricity	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Gas	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Ground	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Heavy fuel oil	0,05%	0,05%	0,05%	0,05%	0,11%	0,11%
Light fuel oil	0,04%	0,04%	0,04%	0,04%	0,08%	0,08%
Peat	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Unknown	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wood	1,56%	1,59%	1,63%	1,68%	3,43%	3,33%
CO2						
	2007	**2013**	**2020**	**2030**	**2020 nuclear**	**2030 nuclear**
Coal	0,03%	0,03%	0,03%	0,04%	0,12%	0,12%
Electricity	0,42%	0,43%	0,44%	0,45%	1,56%	1,47%
Gas	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%
Ground	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Heavy fuel oil	0,02%	0,02%	0,02%	0,02%	0,08%	0,07%
Light fuel oil	0,21%	0,22%	0,22%	0,23%	0,78%	0,73%
Peat	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Unknown	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wood	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

As the table 28 shows, heating methods which are based on wood burning will affect the fine particle emissions the most. Changes in the electricity and light fuel oil heating will affect the overall carbon dioxide emissions the most.

5. Conclusions

The main purpose of this study was to calculate the carbon dioxide and fine particle emissions of the small scale district heating units and the other heating methods in use in Helsinki Metropolitan area in years 2013, 2020 and 2030. Secondary goal of this study was to estimate affects of the emission trading to production costs of the district heating units and what affects would the possible new nuclear plant have.

The thermal energy consumption of district heating has been around 12 TWh each year In Helsinki Metropolitan area. In this study is calculated that the total consumption of thermal energy will increase about 940 GWh in Helsinki Metropolitan area to year 2030. If the fraction of the district heating would remain at 2007 level, the energy consumption of the district heating supply would increase 615 GWh to year 2030. This would mean 27 GWh increase in the energy consumption of district heating suplly each year, which has been 40 GWh in the past 8 years.

Based on the calculations, the model shows that increasing district heating fraction of thermal energy production would reduce the fine particle and carbon dioxide emissions of the other heating methods in use in Helsinki Metropolitan area, but would not have affect to the emissions of the small scale district heating units.

The carbon dioxide emissions of the small scale distinct heating units can be estimated to remain at 2007 level, because almost the small scale district heating units are used in separate district heating networks or are only used in emergencies. The emissions of the small scale district heating units proportion of the overall emissions of the energy production will be less than 1 %. In the future, the carbon dioxide emissions of the small scale district heating units are calculated to be 20 - 30 000 tons and the fine particle emissions 20 – 30 kg each year. Small changes will occur, because of the changes in weather. Emission trading will not affect much the small scale district heating units.

The fine particle emissions of the other heating methods in use are higher than the fine particle emissions of the district heating supply. In the calculations, the fine particle emissions of the other heating methods in use are about 500 tons and carbon dioxide emissions are 600 000 tons in 2007. These emissions are highly dependent of the extension of the district heating network. If district heating network is not extended at all from the year 2007 situation, the overall fine particle emissions of the other heating methods in use will be almost double in the year 2030. If the district heating is extended, so that the buildings heated by district heating would keep the same proportion of the total floor area as it was in the year 2007, then the emissions will increase about 9-10 %. If district heating network is extended so district heating buildings floor area fraction of total floor area in cities increases as in figure 15, then fine particle emissions would degrease about 14 % and carbon dioxide emissions 6 %.

In this study, it is also estimated that proportions of the other heating methods in use are what they were in the year 2007. The future proportions of these heating methods are hard to estimate, because of the future changes like changes in fuel price and emission trading. Table 27 shows how the changes in heating methods will affect the overall carbon dioxide and fine particle emissions.

Extending the district heating network will degrease the overall fine particle emissions in Helsinki Metropolitan area. If the extension costs of district heating network are allocated to be the fine particle reduction cost, the reduction cost is 27 - 68 €/$kg_{PM2,5}$. Which are considerably higher than the fine particle reduction costs by traditional reduction systems, but in these calculations the reduced cost of the other heating methods side are not taken into account. For closer cost estimations the affect of extending the district heating to the other heating methods in use should be assessed.

The costs of the new nuclear plant are calculated to be competitive with the other thermal energy production methods. The price of energy in the new nuclear plant is calculated to be 33-35 €/MW, which is one of the cheapest ways to produce energy. The effect of emission trading will increase fuel prices 2-23 €/MWh depending the fuel and the price of emission right.

In emission trading point of view, it would be best to increase the use of renewable fuels in energy production, because coal, peat and fuel oils effect the overall carbon dioxide emissions the most. Reducing the use of the wood based fuels would be most beneficial to health; because the fine particle emissions would be considerably lower. Also based on the model, the extension of the district heating network would reduce the fine particle emissions in the area. In the future, it would be wise to examine the possibility to connect the possible new nuclear plant to the district heating network of Helsinki Metropolitan area and increase the use of the district heating. This would be the most efficient way to reduce the overall carbon dioxide and fine particle emissions.

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ANNEXES

ANNEX 1. POPULATION CHANGES CALCULATIONS AND ESTIMATIONS FOR THE FUTURE.

Statistics of Finland

	Population Espoo - Esbo	Helsinki - Helsingfors	Kauniainen - Grankulla	Vantaa - Vanda
1987	164569	490034	7790	149063
1988	167734	489965	7877	151157
1989	169851	490629	7897	152262
1990	172629	492400	7889	154933
1991	175670	497542	7948	157274
1992	179054	501514	8233	159213
1993	182647	508588	8268	161103
1994	186507	515765	8305	164376
1995	191247	525031	8298	166480
1996	196260	532053	8464	168778
1997	200834	539363	8515	171297
1998	204962	546317	8530	173860
1999	209667	551123	8549	176386
2000	213271	555474	8532	178471
2001	216836	559718	8543	179856
2002	221597	559716	8582	181890
2003	224231	559330	8622	184039
2004	227472	559046	8465	185429
2005	231704	560905	8457	187281
2006	235019	564521	8469	189711
2007	238047	568531	8511	192522
2008	241024,3	576122,3	9001,76	198160,3
2009	244493,4	578703,4	9060,48	200621,4
2010	247962,6	581284,4	9119,2	203082,6
2011	251431,8	583865,4	9177,92	205543,8
2012	254900,9	586446,5	9236,64	208004,9
2013	258370,1	589027,5	9295,36	210466,1
2014	261883,2	592370,8	9332,208	212927,2
2015	265308,4	594189,6	9412,8	215388,4
2016	268777,6	596770,6	9471,52	217849,6
2017	272246,7	599351,7	9530,24	220310,7
2018	275715,9	601932,7	9588,96	222771,9
2019	279185	604513,8	9647,68	225233
2020	282654,2	607094,8	9706,4	227694,2
2021	286123,4	609675,8	9765,12	230155,4
2022	289592,5	612256,9	9823,84	232616,5
2023	293061,7	614837,9	9882,56	235077,7
2024	296530,8	617419	9941,28	237538,8
2025	300000	620000	10000	240000
2026	303469,2	622581	10058,72	242461,2
2027	306938,3	625162,1	10117,44	244922,3
2028	310407,5	627743,1	10176,16	247383,5
2029	313876,6	630324,2	10234,88	249844,6
2030	317345,8	632905,2	10293,6	252305,8

The year 2025 estimations is taken from Helsinki Metropolitan Council’s report.

ANNEX 2. CALCULATIONS FOR THE FLOOR AREA CHANGES.

Floor area future estimation						
	2000	2007	2013	2020	2025(*	2030
Helsinki	40815573	43557356	45902071	48637571	50591500	52545429
Espoo	13453156	16098692	17929395	20065214	21590800	23116386
Kauniainen	487744	585600	632067	686278	725000	763722
Vantaa	11990387	14075129	15364086	16867869	17942000	19016131
Total	66746860	74316777	79827618	86256933	90849300	95441668

*Taken from YTV-report

Base Scenario

If no new DH buildings are made

District heating buildings floor area

	2007 [m2]	2013 [m2]	2020 [m2]	2025 [m2]	2030 [m2]
Helsinki	37346833	37346833	37346833	37346833	37346833
Espoo	10887366	10887366	10887366	10887366	10887366
Kauniainen	239437	239437	239437	239437	239437
Vantaa	9641925	9641925	9641925	9641925	9641925
Total	58115561	58115561	58115561	58115561	58115561

Scenario 1

If DH fraction of the floor area is same as in 2007

District heating buildings floor area

	2007 [m2]	2013 [m2]	2020 [m2]	2025 [m2]	2030 [m2]
Helsinki	37346833	39357232	41702698	43378030	45053363
Espoo	10887366	12125450	13569881	14601617	15633354
Kauniainen	239437	258436	280601,6	296434,13	312266,7
Vantaa	9641925	10524903	11555044	12290858	13026673
Total	58115561	62266021	67108224	70566940	74025657

Scenario 2

If DH fraction of the floor area is estimated to increase as it has between year 2000-2007

District heating buildings floor area

	2007 [m2]	2013 [m2]	2020 [m2]	2025 [m2]	2030 [m2]
Helsinki	37346833	39613825	42291781	44226451	46179326
Espoo	10887366	12209219	13773001	14904244	16047367
Kauniainen	239437	268538,5	304367,5	331197,53	359059
Vantaa	9641925	11564231	13614064	15178440	16826323
Total	58115561	63655813	69983213	74640333	79412074

ANNEX 3. FLOOR AREA AND HEATING METHOD STATISTICS.

Area, intended use	Total floor area Floor area [m2]	District Heating Floor area [m2]	Other used heating methods Floor area [m2]	Light fuel oil Floor area [m2]	Heavy fuel oil Floor area [m2]	Gas Floor area [m2]
Helsinki	Helsinki	Helsinki	Helsinki	Helsinki	Helsinki	Helsinki
Total	43557356	37346833	6210523	2157986	190151	37711
Separate residential houses	3171761	728094	2443667	787750	6331	1060
Rowhouses	2011487	1281320	730167	257973	15175	685
Appartment houses	20868064	20126214	741850	332092	112451	-
Commercial buildings	1663732	1502640	161092	84492	215	15056
Offices	5474686	5269792	204894	88699	13428	-
Transportation buildings	1503869	807605	696264	68544	8182	2280
Medical buildings	1102358	1025303	77055	29672	1305	-
Meeting houses	1085188	987889	97299	44763	857	169
Schools	1871725	1707991	163734	112267	744	-
Industrial buildings	3375410	2881347	494063	259034	27653	18461
Warehouses	1158617	872819	285798	86206	2799	-
Other buildings	270459	155819	114640	6494	1011	-
Espoo	Espoo	Espoo	Espoo	Espoo	Espoo	Espoo
Total	16098692	10887366	5211326	1753213	152600	23725
Separate residential houses	4255512	849487	3406025	928286	6935	137
Rowhouses	1778996	1307641	471355	182778	1662	-
Appartment houses	4745013	4560706	184307	148348	7422	-
Commercial buildings	802529	694281	108248	65698	1612	-
Offices	1483191	1350208	132983	64247	9581	285
Transportation buildings	285339	69771	215568	30897	-	-
Medical buildings	327601	215489	112112	31529	64380	-
Meeting houses	306192	211713	94479	40806	11433	-
Schools	923696	838304	85392	76036	-	-
Industrial buildings	673654	477289	196365	114174	2468	11058
Warehouses	421536	237759	183777	67041	47040	12245
Other buildings	95433	74718	20715	3373	67	-
Kauniainen	Kauniainen	Kauniainen	Kauniainen	Kauniainen	Kauniainen	Kauniainen
Total	585600	239437	346163	177313	25490	0
Separate residential houses	267959	58084	209875	92387	380	-
Rowhouses	90858	44361	46497	30456	-	-
Appartment houses	115619	83178	32441	24190	6470	-
Commercial buildings	19718	12027	7691	7621	-	-
Offices	6457	1729	4728	4728	-	-

Transportation buildings	2821	1199	1622	1360	-	-
Medical buildings	28082	5636	22446	5485	16602	-
Meeting houses	11285	5035	6250	2720	-	-
Schools	30419	21116	9303	5010	2038	-
Industrial buildings	3678		3678	2690	-	-
Warehouses	26		26	-	-	-
Other buildings	8678	7072	1606	666	-	-
Vantaa	Vantaa	Vantaa	Vantaa	Vantaa	Vantaa	Vantaa
Total	14075129	9641925	4433204	1443524	113315	10433
Separate residential houses	3124651	419018	2705633	760911	4347	293
Rowhouses	1186946	807291	379655	76866	-	-
Appartment houses	4196452	4002029	194423	114402	31583	-
Commercial buildings	694666	625539	69127	54157	583	-
Offices	745885	642105	103780	22531	17274	-
Transportation buildings	565871	389663	176208	42611	4034	296
Medical buildings	239160	208129	31031	22469	739	-
Meeting houses	174810	132334	42476	12103	-	-
Schools	461194	381167	80027	43471	1705	-
Industrial buildings	1327281	952820	374461	206727	37196	6089
Warehouses	1309425	1055416	254009	75857	15506	3755
Other buildings	48788	26414	22374	11419	348	-

Electricity Floor area [m2]	Coal Floor area [m2]	Wood Floor area [m2]	Peat Floor area [m2]	Ground heat Floor area [m2]	Other-unknown Floor area [m2]
Helsinki	Helsinki	Helsinki	Helsinki	Helsinki	Helsinki
2507509	67976	86298	-	20335	1142557
1505189	45246	34429	-	20012	43650
442240	150	5084	-	-	8860
147826	8351	34259	-	-	106871
30976	561	1685	-	-	28107
31087	923	-	-	-	70757
110935	1011	2806	-	-	502506
19741	882	1457	-	-	23998
28691	700	998	-	-	21121
18431	8768	522	-	323	22679
92629	1258	151	-	-	94877
71002	126	421	-	-	125244
8762	-	4486	-	-	93887
Espoo	Espoo	Espoo	Espoo	Espoo	Espoo
2746060	58349	62418	226	114693	300042
2212780	55286	54480	226	113164	34731
284398	836	158	-	-	1523

20466	-	340	-	-	7731
33678	1605	1623	-	-	4032
52262	240	228	-	-	6140
29862	-	359	-	460	153990
14079	102	118	-	-	1904
28330	-	1083	-	-	12827
4442	-	390	-	-	4524
37061	80	1826	-	1069	28629
15924	-	1135	-	-	40392
12778	200	678	-	-	3619
Kauniainen	Kauniainen	Kauniainen	Kauniainen	Kauniainen	Kauniainen
125180	2897	3611	415	4702	6555
101201	2017	3611	415	4702	5162
16041	-	-	-	-	-
400	880	-	-	-	501
70	-	-	-	-	-
-	-	-	-	-	-
262	-	-	-	-	-
359	-	-	-	-	-
3530	-	-	-	-	-
1879	-	-	-	-	376
472	-	-	-	-	516
26	-	-	-	-	-
940	-	-	-	-	-
Vantaa	Vantaa	Vantaa	Vantaa	Vantaa	Vantaa
2414035	37781	43592	358	58513	311653
1776769	28140	40014	358	54630	40171
296051	-	180	-	427	6131
18501	-	-	-	-	29937
12196	130	40	-	-	2021
60413	361	-	-	-	3201
49362	-	167	-	-	79738
7543	-	280	-	-	-
18353	-	105	-	-	11915
13766	8993	662	-	-	11430
63968	-	44	-	322	60115
94524	-	2010	-	3134	59223
2589	157	90	-	-	7771

ANNEX 4. LIST OF THE MODEL VARIABLES.

Free Parameters

Parameter	**Value**	**Explanation**
DH	1809,3	[GWh] In Espoo need for district heating
expKau	73,2	[GWh] Exported district heat to Kauniainen from Espoo
inport	5,7	[GWh] Inported district heating to Espoo
over	1950,1	[GWh] In Espoo over 50 MW district heating platns produced heat
under	67,9	[GWh] In Espoo less than 50 MW district heating plants produced heat
DH	6409,8	[GWh] In Helsinki need for district heating
expEsp	5,7	[GWh] Exported district heat to Espoo from Helsinki
expVan	19,2	[GWh] Exported district heat to Vantaa from Helsinki
inport	8,4	[GWh] Inported district heat to Helsinki
over	6855,5	[GWh] In Helsinki over 50 MW district heating plants produced heat
under	0	[GWh] In Helsinki less than 50 MW district heating plants produced heat
Districtheating	73,2	[GWh] In Kauniainen need for district heating
inport	73,2	[GWh] Inported district heat to Kauniainen
DH	1458,9	[GWh] In Vantaa need for district heating
ExpAir	97,7	[GWh] Exported district heat to Airport's DH network from Vantaa
expHel	8,4	[GWh] Exported district heat to Helsinki from Vantaa
ExpKer	22,1	[GWh] Exported district heat to Kerava from Vantaa
inport	19,2	[GWh] Inported district heat to Vantaa
over	1510,2	[GWh] In Vantaa over 50 MW district heating plants produced heat
under	57,7	[GWh] In Vantaa less than 50 MW district heating plants produced heat
inport	5,7	[GWh] Inported district heat to Espoo
Otherheating	851,95	[GWh] In Espoo other heating methods produced heat
Inport	8,4	[GWh] Inported district heat to Helsinki
Otherheating	1047,89	[GWh] In Helsinki other heating methods produced heat
Districtheating	73,2	[GWh] In Kauniainen need for district heating
Otherheating	102,93	[GWh] In Kauniainen other heating methods produced heat
Disti	1567,9	[GWh] In Vantaa produced district heat
ExpHel2	0	[GWh] Exported district heat to Helsinki from Vantaa, if theres more district heat availab
ExportHelsinki	8,4	[GWh] Exported district heat to Helsink from Vantaa
Otherheating	659,25	[GWh] In Vantaa other heating methods produced heat
Coal	1023,952034	[GWh] In Espoo over 50 MW DH plants produced thermal energy from coal
Heavyfuel	79,06463599	[GWh] In Espoo over 50 MW DH plants produced thermal energy from heavy fuel oil
Lightfuel	4,329222	[GWh] In Espoo over 50 MW DH plants produced thermal energy from light fuel oil
Naturalgas	842,7474156	[GWh] In Espoo over 50 MW DH plants produced thermal energy from natural gas
Over	1950,1	[GWh] In Espoo over 50 MW DH plants produced thermal energy
Coal	2847,026765	[GWh] In Helsinki over 50 MW DH plants produced thermal energy from coal
Heatpump	25,159685	[GWh] In Helsinki over 50 MW DH plants produced thermal energy by heat pumps
Heavyfuel	103,10672	[GWh] In Helsinki over 50 MW DH plants produced thermal energy from heavy fuel oil
Lightfuel	0,151849325	[GWh] In Helsinki over 50 MW DH plants produced thermal energy from light fuel oil
Naturalgas	3878,697935	[GWh] In Helsinki over 50 MW DH plants produced thermal energy from natural gas
Over	6855,5	[GWh] In Helsinki over 50 MW DH plants produced thermal energy
Coal	543,7305807	[GWh] In Vantaa over 50 MW DH plants produced thermal energy from coal
Heavyfuel	14,5039608	[GWh] In Vantaa over 50 MW DH plants produced thermal energy from heavy fuel oil
Lightfuel	0	[GWh] In Vantaa over 50 MW DH plants produced thermal energy from light fuel oil
Naturalgas	980,9715528	[GWh] In Vantaa over 50 MW DH plants produced thermal energy from natural gas
Over	1510,2	[GWh] In Vantaa over 50 MW DH plants produced thermal energy

Fixed parameters

Parameter	**Value**	**Explanation**
Disti	2018	[GWh] In Espoo produced district heat
Districtheating	1809,3	[GWh] In Espoo need for district heating
exportKauniaine	73,2	[GWh] District heating that is trasfered from Espoo to Kauniainen

Over50DH	1951,56744	[GWh] In Espoo over 50 MW district heating plants produced heat
Under50DH	66,43256	[GWh] In Espoo less than 50 MW district heating plants produced heat
Disti	6855,5	[GWh] In Helsinki produced district heat
Districtheating	6409,8	[GWh] In Helsinki need for district heating
ExpEsp2	-6414,9	[GWh] Esported district heat to Espoo from Helsinki, if theres more district heat than needed in Hel
ExpEspoo	5,7	[GWh] Exported district heat to Espoo from Helsinki
ExportVantaa	19,2	[GWh] Exported district heat to Vantaa from Helsinki
ExpVanta2	-3501,57	[GWh] Esported district heat to Vantaa from Helsinki, if theres more district heat than needed in He
Over50	6855,5	[GWh] In Helsinki over 50 MW district heating plants produced heat
Under50	0	[GWh] In Helsinki less than 50 MW district heating plants produced heat
inport	73,2	[GWh] Inported district heat to Kauniainen
DHover50	1508,398195	[GWh] In Vantaa over 50 MW district heating plants produced heat
DHunder50	59,501805	[GWh] In Vantaa less than 50 MW district heating plants produced heat
Districtheating	1458,9	[GWh] In Vantaa need for district heating
ExpHel	8,4	[GWh] Esported district heat to Helsinki from Vantaa
ExportKerava	22,1	[GWh] Exported district heat to Kerava from Vantaa
Lessthan50Espoo	65,998	[GWh] Small-scale district heating units produced thermal energy in Espoo
Lessthan50Vanta	59,5	[GWh] Small-scale district heating units produced thermal energy in Vantaa
Lessthan50Helsi	0	[GWh] Small-scale district heating units produced thermal energy in Helsinki
OtherheatingEsp	851,95	[GWt] In Espoo other heating methods produced heat
OtherheatingHel	1047,89	[GWt] In Helsinki other heating methods produced heat
OtherheatingKau	102,93	[GWt] In Kauniainen other heating methods produced heat
OtherheatingVan	659,25	[GWt] In Vantaa other heating methods produced heat
NuclearHelsinki	0	[GWh] Produced district heat in the nuclear plant, which is placed to Loviisa

Global parameters

Parameter	**Parameters Value**	**Unit of the parameter and describtion**
Airport	4,6	[GWh] In Vantaa Airport backup heating units produced heat
Auroranportti	0,5	[GWh] In Espoo Auroranportti backup heating untis produced heat
ExpAirport	97,7	[GWh] Exported district heat to Helsinki-Vantaa airport from Vantaa's district heating network
ExpKerava	22,1	[GWh] Exported district heat to Kerava's network from Vantaa
Fazer	30	[GWh] Amount of thermal energy that Fazer-heating unit produces each year
HeatDemandEspoo	2661,3	[GWh] Total need for heating in Espoo
HeatDemandHelsinki	7457,7	[GWh] Total need for heating in Helsinki
HeatDemandKauniainen	176,13	[GWh] Total need for heating in Kauniainen
HeatDemandVantaa	2118,2	[GWh] Total need for heating in Vantaa
HK	17	[GWh] Amount of thermal energy that HK-ruokatalo-heating unit produces each year
InportEspoo	5,7	[GWh] Inported district heat to Espoo from Helsinki
InportHelsinki	8,4	[GWh] Inported district heat to Helsinki from Vantaa
InportVantaa	19,2	[GWh] Inported district heat to Vatnaa from Helsinki
Juvanmalmi	36	[GWh] Amount of thermal energy that Juvanmalmi-heating unit produces each year
Kalajärvi	6,2	[GWh] Amount of thermal energy that Kalajärvi-heating unit produces each year
Katriina	6,1	[GWh] Amount of thermal energy that Katriina-heating unit produces each year
Kirkkonummi	1,2	[GWh] In Espoo Kirkkonummi backup heating units produced heat
LossesEspoo	141,2	[GWh] Espoo's distict heating networks yearly heat losses
LossesHelsinki	429,2	[GWh] Helsinki's district heating networks yearly heat losses
LossesKauniainen	0	[GWh] Kauniainen's district heating networks yearly heat losses (part of Espoo's district heating ne
LossesVantaa	148	[GWh] Vantaa's district heating networks yearly heat losses
Masala	7	[GWh] In Espoo Masala heating untis produced heat
Metsola	0	[GWh] In Vantaa Metsola backup heating units produced heat
NuclearHeat	0	[GWh] Produced heat in possible new nuclear plant, which is connected to Helsinki metropolitan area
Pähkinärinne	0	[GWh] In Vantaa Pähkinärinne backup heating units produced heat
Salmisaari	0	[GWh] Amount of thermal energy that Salmisaari-eidheating unit produces each year
Suomenoja	17	[GWh] Amount of thermal energy that Suomenoja-aidheating unit produces each year
Viinikkala	0	[GWh] Amount of thermal energy that Viinikkala-heating unit produces each year

CoalHeatEspoo	0,010518	[%/100] In Espoo coal heated buildings floor area portion of the other heating methods total floor a
CoalHeatHelsinki	0,010174	[%/100] In Helsinki coal heated buildings floor area portion of the other heating methods total floo
CoalHeatKauniainen	0,0079278	[%/100] In Kauniainen coal heated buildings floor area portion of the other heating methods total fl
CoalHeatVantaa	0,0080991	[%/100] In Vantaa coal heated buildings floor area portion of the other heating methods total floor
DHover50Espoo	0,96708	[%/100] In Espoo over 50 MW district heating plants portion of the total produced district heat
DHover50Vantaa	0,96205	[%/100] In Vantaa over 50 MW district heating plants portion of the total produced district heat
DHpersentEspoo	0,67987	[%/100] In Espoo district heated buildings floor area portion of the total floor area
DHpersentHelsinki	0,85949	[%/100] In Helsinki district heated buildings floor area portion of the total floor area
DHpersentKauniainen	0,4156	[%/100] In Kauniainen district heated buildings floor area portion of the total floor area
DHpersentVantaa	0,68876	[%/100] In Vantaa district heated buildings floor area portion of the total floor area
ElectricityHeatEspoo	0,495	[%/100] In Espoo electrically heated buildings floor area portion of the other heating methods total
ElectricityHeatHelsinki	0,3753	[%/100] In Helsinki electrically heated buildings floor area portion of the other heating methods to
ElectricityHeatKauniainen	0,34256	[%/100] In Kauniainen electrically heated buildings floor area portion of the other heating methods
ElectricityHeatVantaa	0,5175	[%/100] In Vantaa electrically heated buildings floor area portion of the other heating methods tota
GasHeatEspoo	0,0042766	[%/100] In Espoo gas heated buildings floor area portion of the other heating methods total floor ar
GasHeatHelsinki	0,0056443	[%/100] In Helsinki gas heated buildings floor area portion of the other heating methods total floor
GasHeatKauniainen	0	[%/100] In Kauniainen gas heated buildings floor area portion of the other heating methods total flo
GasHeatVantaa	0,0022365	[%/100] In Vantaa gas heated buildings floor area portion of the other heating methods total floor a
GroundHeatEspoo	0,020674	[%/100] In Espoo ground heated buildings floor area portion of the other heating methods total floor
GroundHeatHelsinki	0,0030436	[%/100] In Helsinki ground heated buildings floor area portion of the other heating methods total fl
GroundHeatKauniainen	0,012867	[%/100] In Kauniainen ground heated buildings floor area portion of the other heating methods total
GroundHeatVantaa	0,012543	[%/100] In Vantaa ground heated buildings floor area portion of the other heating methods total floo
HeavyFuelHeatEspoo	0,027508	[%/100] In Espoo heavy fuel oil heated buildings floor area portion of the other heating methods tot
HeavyFuelHeatHelsinki	0,02846	[%/100] In Helsinki heavy fuel oil heated buildings floor area portion of the other heating methods
HeavyFuelHeatKauniainen	0,069755	[%/100] In Kauniainen heavy fuel oil heated buildings floor area portion of the other heating method
HeavyFuelHeatVantaa	0,024291	[%/100] In Vantaa heavy fuel oil heated buildings floor area portion of the other heating methods to
LightFuelHeatEspoo	0,31603	[%/100] In Espoo light fuel oil heated buildings floor area portion of the other heating methods tot
LightFuelHeatHelsinki	0,32299	[%/100] In Helsinki light fuel oil heated buildings floor area portion of the other heating methods
LightFuelHeatKauniainen	0,48523	[%/100] In Kauniainen light fuel oil heated buildings floor area portion of the other heating method
LightFuelHeatVantaa	0,30945	[%/100] In Vantaa light fuel oil heated buildings floor area portion of the other heating methods to
NuclearHelsinkiVantaa	0,55	[%/100] Portion of excess heat in Helsinki, which is transferred to Vantaa
Over50EspooCoal	0,52508	[%/100] Energy produced from Coal fraction of the large-scale DH units production in Espoo
Over50EspooHeavyfuel	0,040544	[%/100] Energy produced from Heavy fuel oil fraction of the large-scale DH units production in Espoo
Over50EspooLightfuel	0,00222	[%/100] Energy produced from Light fuel oil fraction of the large-scale DH units production in Espoo
Over50EspooNatural	0,43216	[%/100] Energy produced from Natural gas fraction of the large-scale DH units production in Espoo
Over50HelsinkiCoal	0,41529	[%/100] Energy produced from Coal fraction of the large-scale DH units production in Helsinki
Over50Helsinkiheatpumps	0,00367	[%/100] Energy produced by geothermal heating fraction of the large-scale DH units production in Helsinki
Over50HelsinkiHeavyfuel	0,01504	[%/100] Energy produced from Heavy fuel oil fraction of the large-scale DH units production in Helsinki

Over50HelsinkiLightfuel	2,22E-05	[%/100] Energy produced from Light fuel oil fraction of the large-scale DH units production in Helsinki
Over50HelsinkiNatural	0,56578	[%/100] Energy produced from Natural gas fraction of the large-scale DH units production in Helsinki
Over50VantaaCoal	0,36004	[%/100] Energy produced from Coal fraction of the large-scale DH units production in Vantaa
Over50VantaaHeavyfuel	0,009604	[%/100] Energy produced from Heavy fuel oil fraction of the large-scale DH units production in Vantaa
Over50VantaaLightfuel	0	[%/100] Energy produced from Light fuel oil fraction of the large-scale DH units production in Vantaa
Over50VantaaNatural	0,64956	[%/100] Energy produced from Natural gas fraction of the large-scale DH units production in Vantaa
PeatHeatEspoo	0	[%/100] In Espoo peat heated buildings floor area portion of the other heating methods total floor a
PeatHeatHelsinki	0	[%/100] In Helsinki peat heated buildings floor area portion of the other heating methods total floo
PeatHeatKaunainen	0,0011357	[%/100] In Kauniainen peat heated buildings floor area portion of the other heating methods total fl
PeatHeatVantaa	7,67E-05	[%/100] In Vantaa peat heated buildings floor area portion of the other heating methods total floor
Pähkinärinne	0	[%/100] In Vantaa Pähkinärinne-heating units produced heat portion of the needed backup heat in les
UnknownEspoo	0,054085	[%/100] In Espoo unknown heating methods buildings floor area portion of the other heating methods t
UnknownHelsinki	0,17101	[%/100] In Helsinki unknown heating methods buildings floor area portion of the other heating method
UnknownKauniainen	0,017938	[%/100] In Kauniainen unknown heating methods buildings floor area portion of the other heating meth
UnknownVantaa	0,066809	[%/100] In Vantaa unknown heating methods buildings floor area portion of the other heating methods
WoodHeatEspoo	0,071864	[%/100] In Espoo wood heated buildings floor area portion of the other heating methods total floor a
WoodHeatHelsinki	0,083373	[%/100] In Helsinki wood heated buildings floor area portion of the other heating methods total floo
WoodHeatKauniainen	0,062589	[%/100] In Kauniainen wood heated buildings floor area portion of the other heating methods total fl
WoodHeatVantaa	0,058998	[%/100] In Vantaa wood heated buildings floor area portion of the other heating methods total floor