Sergei Saprunov

CALCULATION OF THE PRIMARY ENERGY FACTOR FOR FINNISH DISTRICT HEATING AND ELECTRICITY

Bachelor's thesis
Building Services Engineering

2017

XAMK

South-Eastern Finland
University of Applied Sciences

Author	Degree	Time
Sergei Saprunov	Building Services Engineering	May 2017

Title	
Calculation of the primary energy factor for Finnish district heating and electricity	61 pages 22 pages of appendices

Commissioned by

Supervisor

Mika Ruponen

Abstract

Today reduction of energy consumption and increasing of energy efficiency are common trends needed in order to achieve sustainability. For residential buildings this aim can be achieved by replacing windows, improving insulation and by renovatimg of HVAC systems. However, that improvements affect only the final elements of energy distribution chain. Such chain elements as energy needed to extract energy sources, energy needed to transport energy sources and energy needed to produce fuel out of energy sources are receiving much less attention than attempts to reduce buildings energy consumption.

Idea of the work is to look at the situation from different point of view and switch attention from the requirements for energy consumers to the requirements for energy suppliers. That approach will show how strong energy suppliers could affect energy efficiency. In order to express efficiency of electricity generation and district heat generation in a numerical form a so-called primary energy factor is used. Primary energy factor reflects ratio between amount of primary energy that is needed to produce electricity or district heat and final produced energy.

The study is focused on the application of primary energy factor to the Finnish electricity and Finnish district heating in order to compare efficiency of the district heating to the efficiency of electricity nowadays and make forecast about their efficiencies in the future. Another aim is to compare primary energy factor with main climate and energy indicators used by Eurostat. On the basis of this work, it could be asserted about a significant influence of the primary energy factor on the energy performance. Primary energy factor is an instrument to track and control efficiency of heat and electricity generation that can be used to control energy sustainability.

Keywords

Primary Energy Factor, PEF calculation, PEF calculation for Finnish electricity network, PEF calculation for Finnish district heating network, PEF forecast

CONTENTS

APPENDICES

LIST OF TERMS

Calorific value – the amount of heat released by a unit weight or unit volume of a substance during combustion.

CHP – combined heat and power. A system which combines heat production with electricity production by using waste heat in vapor form for electricity generation in order to improve efficiency.

CHPP – combined heat and power plant. A power plant based on the combined heat and power principle.

DH – district heating. System, which distributes heat in a liquid form by using pipe network. Heat is distributed from heating plant to the costumers.

Ecoheatcool – project that unites district heating, district cooling, offers higher energy efficiency and higher security of supply with the benefit of lower carbon dioxide emissions by analyzing the heating and cooling demands in Europe.

Energy carrier – substance or energy form that contains energy, which can be converted to another energy forms such as electricity or heat.

E-value – indicator that represents total energy consumption of the building. E-value (kWh/m2) is the calculated annual net purchased energy consumption of the building accentuated with the coefficients of the energy forms with the rules and initial values provided in the D3 National Building Code of Finland.

Energy form coefficients – coefficients of the energy sources or the forms of energy production, which are used for energy value calculations.

Eurostat – statistical office of the EU. Eurostat provides different statistics that makes possible comparing of different EU countries by using united statistics.

FE – final energy. Final energy is showing an amount of energy available for user after conversion of primary energy.

GEMIS – global emission models for integrated systems. GEMIS is a model and a database for life-cycle analysis. It evaluates environmental impacts of energy, material and transport systems. It was used for primary energy factor calculation with taking all energy inputs into account.

GHGE – greenhouse gas emissions. Greenhouse gas emission is a negative side effect of the human activities. Greenhouse gases are trapping heat in the atmosphere. Increasement of the greenhouse gases concentration in the atmosphere is considered to be the main reason of greenhouse effect and global warming.

HOB – Heat only boiler, the system that heats water for district heating applications.

IINAS – International Institute for Sustainability Analysis and Strategy. An independent transdisciplinary research organization.

LCA – life-cycle assessment.A technique used to account all environmental impacts. Accounts environmental impact during extraction, distribution, disposal and another possible processing.

NBC D3 – National Building Code of Finland 2012, Section D3 on Energy Management in Buildings.

nZEB – nearly zero-energy buildings. Buildings with high energy efficiency.

PE – primary energy. Primary energy means energy contained in raw fuels and stored in nature before any extraction and transformation processes.

PEF – primary energy factor .A ratio between primary energy consumption and final energy consumption.

PEF non-renewable – primary energy factor used for accounting non-renewable energy. It represents a ratio between non-renewable primary energy consumption and final energy consumption.

PEF renewable – primary energy factor used for accounting renewable energy. It represents a ratio between renewable primary energy consumption and final energy consumption.

PEF total – primary energy factor for sum of non-renewable and renewable energy. That factor is representing a ratio between both renewable consumption, non-renewable primary energy consumption and the final energy consumption.

PRF – primary resource factor. Primary resource factor is defining a ratio between fossil energy supply and energy used in the building. Primary resource factor excludes the renewable part of the primary energy and identical to the PEF non-renewable.

SAP – Standard Assessment Procedure. Great Britain government's Standard Assessment Procedure for Energy Rating of Dwellings that is used to estimate energy performance of the buildings.

1 INTRODUCTION

There are 7.4 billion people living in the world at the current moment of time /1/. Approximated world population in 2100 will be in a range between 9.7 billion and 13.4 billion with a 95% confidence interval /2./ The problem is that humanity currently using the equivalent of 1.6 Earth planets to provide the resources we absorb or waste and nowadays there is no clear way how to stop or decrease Earth's resources depletion. /3./ It means that resources on earth are being depleted faster than naturally restored. Because of the exceeded sustainable population limit time is not on our side anymore. Earth is starting to lose stability in different spheres and right now there is no way to gain it back. It is very important to find the way how to slow down or completely stop that process. /4./ That is the main reason why humanity should keep planet's long-term population capacity as high as possible and provide suitable living conditions for the future generations. /5./

Sustainability is an academic approach to maintaining balance on Earth. Sustainability considers such fields as global warming, energy use trends, environmental policy, water resources and food system. Action in these areas today will result in how well human society will deal with global change, environmental degradation and shortage of resources. In this way improvements in measuring energy efficiency will have a positive impact on Earth sustainability.

That work is about an improvement of the existing approach for measuring energy performance in Finland by achieving more precise values of the E-value indicator. The main idea of the work is to look at the energy performance from less common point of view and to take into account all stages energy generation instead of focusing on the development of low-energy building techniques such as nearly zero-energy buildings (nZEB) or passive houses. The so-called primary energy factor is used as the main tool needed for implementation of this idea. One form of primary energy factor is used in Finnish standards as energy form coefficient.

Finnish National Building Code D3 is using energy form coefficients for E-value calculations /6, p. 8/. Annual consumption of purchased energy for buildings is based on E-values. /7./ In this way, energy form coefficients are used to calculate annual consumption of purchased energy for the buildings. Consequently, annual consumption of purchased energy for buildings has a direct relationship with constant values of energy form coefficients despite the absence of mathematical justification.

The main question of the work is that energy form coefficients are remaining constant since the year 2012. The values of energy form coefficients are not supported by any open source calculations. The purpose of current work is to fill that gap by calculation primary energy factors for Finnish district heating network and Finnish electricity network with further comparison of the obtained values with used energy form coefficients. Another important feature of the work is to forecast future primary energy factor values. Considering the lack of similar works this work can partially fill this gap and increase interest in the use of primary energy factor as sustainability indicator.

2 AIMS

First major goal is to calculate primary energy factor (PEF) for Finnish electricity and Finnish district heat (DH). Second major goal of the current thesis is to compare calculated PEFs for a Finnish DH network and Finnish electricity network with energy coefficients used by Finnish National Building Code D3. Third major goal is to make a forecast about how PEFs for Finnish district heat and electricity will change in the future.

As the work progresses towards accomplishing of major goals following minor goals will be achieved. First minor goal is overview of total PEF, renewable PEF and non-renewable PEF. Second minor goal is studying expediency of replacing Eurostat climate control indicators such as energy efficiency, renewables share and greenhouse gas emissions (GHGE) by PEF. Third minor goal is a review of the Finnish electricity market, Finnish district heat market and overview of energy sources which are used for heat and electricity generation. To sum up, the aim of the thesis is to study the way of Finnish PEF calculation and obtain data, which will give a possibility to discuss benefits and inaccuracies of PEF calculation and PEF use overall.

3 METHODS

To start with, the initial idea of the work was to determine weaknesses of DH network energy efficiency in comparison with electrical heating energy efficiency by using PEF. Thereafter, mainly because the initial approach wasn't correct, the orientation of the work has been switched from district heating weaknesses to the Finnish PEF calculation and PEF overview. In order to make a comparison between PEF of electricity and PEF of DH it is needed to calculate average PEF for Finnish electricity and DH by using already known PEF values for different energy sources.

Before performing PEF calculations it is necessary to figure out what is the idea of PEF, where it is used and how useful it could be to apply PEF for improving energy efficiency. So far as PEF is coefficient with different possible physical meanings that work takes into account all definitions of PEF and determines the most useful definition of PEF to accomplish the goals. Chosen PEF definition has been compared to the main Eurostat climate control indicators. Those indicators are following: energy efficiency, GHGE and renewables share. Obtained results give an ability to define PEF idea and show the physical meaning of the PEF values calculated for the Finnish district heating and electricity networks. In this way, the reader gets an idea about the meaning of calculated PEF values.

For calculating PEF weighted arithmetic mean has been used. Weighted arithmetic mean gives ability to calculate average PEF for electricity and district heating. To perform calculations it is needed to know two variables: share of an energy source in Finland and PEF for a considered energy source. As it was already mentioned, National Building Code D3 doesn't provide any information about both variables and outcome calculation of the energy form coefficients. For this reason information about data sources for both variables is provided in following chapters.

However, there are difficulties that cast doubt on the ability to perform PEF calculations precisely enough and call into question the expediency of this work. Those difficulties could also lead to the low amount of articles about PEF calculation. Firstly, because of the insufficient amount of PEF data for the certain energy sources in different countries, there is need to use assumptions in order to perform calculations. Secondly, there is a lack of information about the way how to perform PEF calculations correctly. Furthermore, it is impossible to calculate PEF values for different energy sources without access to the wide range of databases. Already calculated values were used in the work instead. Moreover, there is a lack of examples how to perform PEF calculation for the combined heat and power (CHP). Finally, the purpose of such calculations is not clear. In spite of these difficulties all mentioned points were taken into account and discussed in the work. Figure 1 illustrates the thesis roadmap.

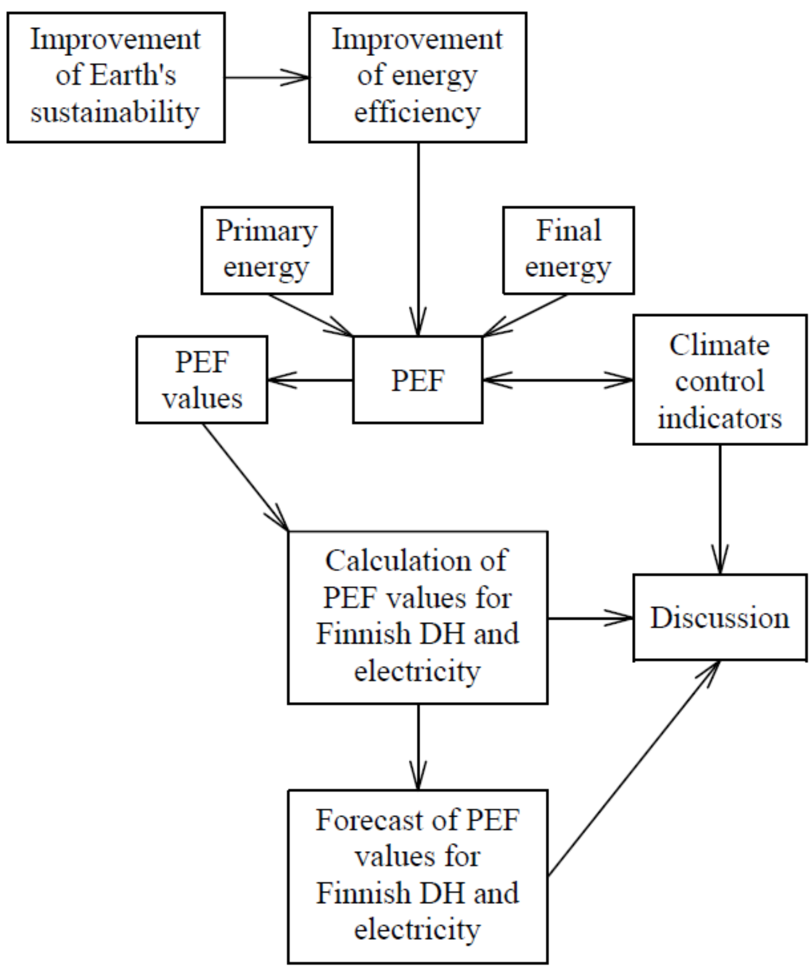


Figure 1. Bachelor’s thesis roadmap

4 PRIMARY ENERGY FACTOR

The current chapter explains what PEF is and provides information about PEF.The chapter starts with basic information about primary energy and final energy. Then it explains accounting options, connection between primary energy and PEF and describes the way how PEF is expressed in the work.The chapter also explains methods and options, which will be used for PEF calculations. Review of the databases used for the PEF calculations and the way how PEF related to the Eurostat climate control indicators are also described in that chapter.

4.1 Primary energy and final energy

Primary energy is an energy contained in fuels and other forms of energy like oil, coal, natural gas, wind and water before any extraction, conversion and transformation processes is called primary energy (PE). Figure 2 shows examples of PE carriers: water in the river as energy form and wood in the forest as combustible fuel.

Figure 2. Examples of primary energy /8, 9/

PE is divided on renewable and non-renewable energy. Energy extracted from sources that are naturally replenishing itself for short amount of time is called renewable energy. For non-renewable energy sources extraction rate is higher than replenishing rate. Energy obtained from non-renewable energy sources is called non-renewable energy. Energy sources can be divided on combustible and non-combustible. Table 1 shows common types of PE sources used for heat and electricity generation.

Table 1. Primary energy sources

Non-renewable energy sources		Renewable energy sources	
Combustible	Non-combustible	Combustible	Non-combustible
Hard Coal, Coal gases, Lignite, Oil based fuels, Natural gas, Waste(fossil part), (Peat)	Nuclear	Biomass (solid, liquid, gaseous), Waste (biogenic part), (Peat)	Hydro (storage, run-of-river, tide, wave and ocean), Wind, Solar (photovoltaic, solar thermal), Geothermal

After conversion process or multiple different conversion processes PE is converted into the final energy (FE). FE is a form of energy available to the user following the conversion from primary energy carriers /10/. Table 2 is showing main energy carriers that are used to deliver FE.

Table 2. Main energy carriers of FE

Non-renewable energy sources		Renewable energy sources	
Combustible	Non-combustible	Combustible	Non-combustible
Enthalpy, mechanical work, electricity	electricity	Enthalpy, mechanical work, electricity	Enthalpy, electricity

4.2 PE and FE accounting

Because of the FE definition, it is the only way how to account FE. Usually, it is accounted by direct measuring of an energy carrier by meter. PE is accounted differently.

There are multiple ways how PE for combustible energy sources and how PEF for non-combustible energy sources should be accounted. According to the Equation 1, PE for combustible energy sources is accounted by multiplying an amount of fuel units on calorific value of the fuel.

$$PE_f = CF_f \cdot Input_f \tag{1}$$

where	CF_f	calorific value of a fuel unit	[MJ/kg]
	PE_f	friction factor	[MWh]
	$Input_f$	amount of weight units	[kg]

For non-combustible energy sources Equation 1 is not applicable. There are four different options how to account PE for electricity and heat generation for non-combustible energy sources (Table 3).

Table 3. Options to account PE for electricity and heat generation from non-combustible energy sources /11, p. 5/

No.	Option	Type of PE
1	The PE for electricity or heat from non-combustible renewables (hydro, wind, solar, geothermal) is accounted as zero by definition	Not applicable
2	PE equivalents used to calculate the PE of non-combustible energies (renewable energies excl. biomass) and the special case of nuclear energy.	Accounting for (total) PE
3	The PE for electricity or heat from renewables only accounts the fossil PE that was necessary to produce construction materials for the infrastructure (e.g. hydropower stations, wind turbines, photovoltaic cells, etc.) including fuels for transport and auxiliary materials during operation. For electricity from nuclear energy, the consumed fuel is also accounted as non-renewable PE using a technical conversion efficiency or a PE equivalent.	Split up into non-renewable (fossil) and renewable PE. Accounting for non-renewable (fossil) PE only
4	The PE is split up into fossil PE (e.g. infrastructure, conversion of nuclear energy) and renewable PE using PE equivalents or efficiencies for the conversion of renewable energy sources into electricity or heat.	Accounting for non-renewable (fossil) and renewable PE.

Both accounted PE and FE are used as main indicators for the EU climate & energy package 2020. The purpose of both PE consumption and FE consumption indicators is tracking progress towards accomplishing energy efficiency aims of the EU climate and energy package 2020. /12./ Eurostat is using primary energy consumption to measure the total energy demand of a countries. PE consumption covers consumption of the energy sector itself, losses during transformation (for example, from oil or gas into electricity) and distribution of energy and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum not used not for combustion but for producing plastics) /13/. Table 4 includes PE calculation methods.

Table 4. PE calculation methods for different options /14, p. 5/

Options defined under this method	Calculation method	Description	Organizations
Option 1	Zero equivalency method	A fixed standard value with no distinction between heat and electricity	very limited use in practice
Sub-Option 2a	Direct equivalent method	Based on technical conversion efficiency	UN statistics and IPCC reports
Sub-Option 2b	Physical energy content method	Compared to primary energy requirement of reference technology	International Energy Agency (IEA), Eurostat, OECD
Sub-Option 2c	Substitution method	Compared to primary energy requirement of reference technology	US Energy Information Administration (EIA)
Option 3,4	Life cycle assessment method	Standardized method that also takes into consideration the complete supply chain and clearly makes a difference between renewable and nonrenewable shares	Not used in energy statistics so far

Final energy consumption is the total energy consumed by end users such as households, industry and agriculture. It is the energy that reaches the final consumer's door excluding energy used by the energy sector itself. Final energy consumption excludes energy used by the energy sector, including for deliveries. It also excludes fuel transformed in the electrical power stations of industrial auto-producers and coke transformed into a blast-furnace gas where this is not part of overall industrial consumption but of the transformation sector /15/. In this way, life cycle assessment (LCA) method is preferred in the work due to its highest precision.

4.3 Primary energy factor

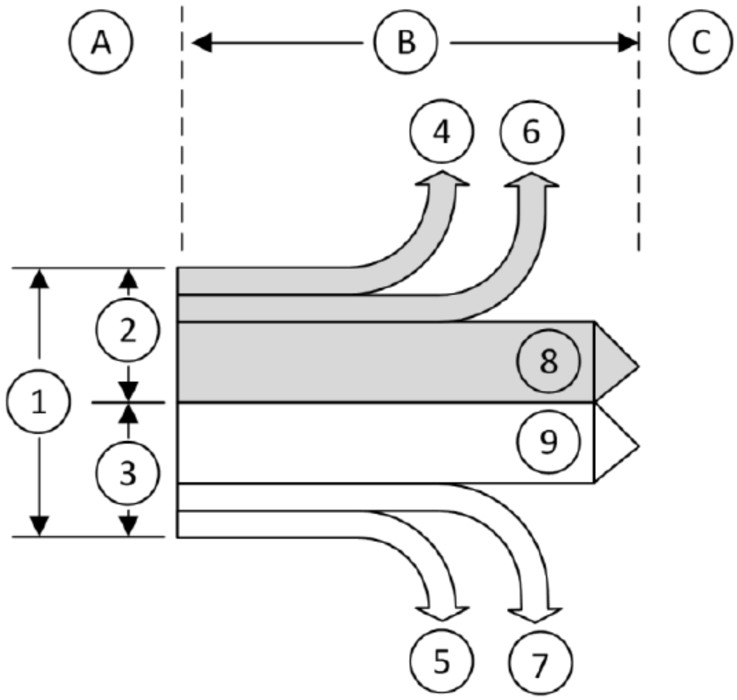
Primary energy factors, often referred to as conversion factors, are required to calculate the total energy consumption including the chain of energy generation based on the final energy consumption data. For each type of delivered energy, a so-called PEF is assigned. In the most useful case, PEF is tracking all energy-relevant demand from initial harvesting to the point of energy delivery. However, it is also possible that PEF can have same meaning as technical conversion efficiency. PEFs have been developed as a form of comparison on how much PE is required in order to deliver one unit of FE. Thereby PEF is calculated by Equation 2 as a ratio of PE to the FE

$$PEF = \frac{PE}{FE} \tag{2}$$

where	PE	real share of renewables	[MWh]
	FE	announced share of renewables	[MWh]

Since there are renewable and non-renewable PE sources PEF is divided on total PEF, renewable PEF and non-renewable PEF. Total PEF is sum of renewable and non-renewable PE divided by FE. Non-renewable PEF is taking into account only non-renewable energy divided by FE. Renewable PEF is taking into account only renewable energy divided by FE.

Figure 3 is showing the way how primary energy factors are connected with assessment boundaries and energy flows.



$$f_{Ptot} = \frac{(1)}{(8)+(9)} \qquad f_{Pnren} = \frac{(2)}{(8)+(9)} \qquad f_{Pren} = \frac{(3)}{(8)+(9)}$$

Figure 3. Primary energy factors and energy flows /16, p. 55/

where A energy source in nature

B upstream chain of energy supply

C inside the assessment boundary

1 total primary energy, shows PEF for sum of the renewable and non-renewable energy

2 non-renewable primary energy, shows PEF for non-renewable energy only

3 renewable primary energy, shows PEF for renewable energy only

4 non-renewable infrastructure related energy

5 renewable infrastructure related energy

6 non-renewable energy to extract, refine, convert and transport

7 renewable energy to extract, refine, convert and transport

8 delivered non-renewable energy

9 delivered renewable energy

In this way, PEF value is depending on calculation boundary and type of energy source. Figure 4 shows an example of the entire supply chain for the electricity production from combustible energy sources. The resource is combustible PE source and electricity is FE carrier.

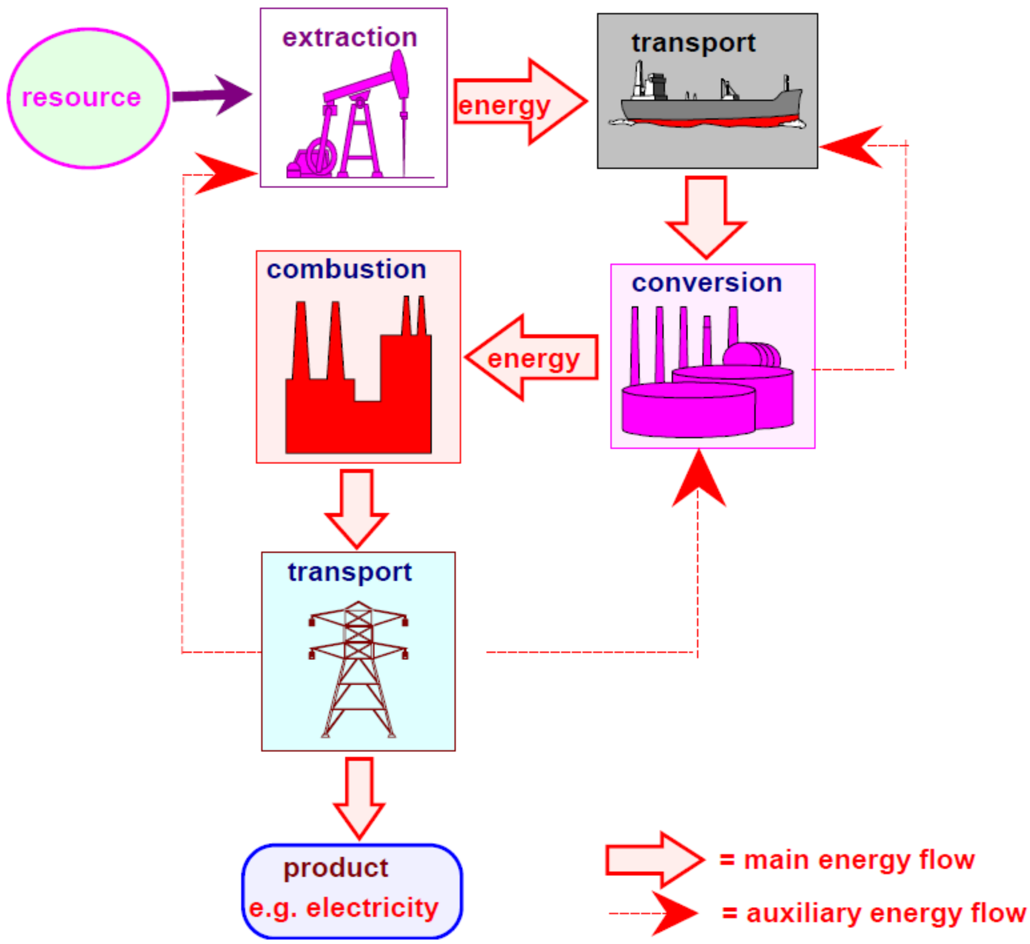


Figure 4. Energy flows of the entire energy supply chain /17, p. 2/

Entire supply chain boundary accounts PE for all direct and indirect energy transformations during electricity generation process. Entire supply chain includes energy spend on extraction, transportation, transformation and considers PE globally. Although there are other boundaries for PEF accounting, only PEFs calculated by entire supply chain boundaries are preferred in the current work. It gives abilities to compare PEFs of different energy sources and consequently most precisely reflects efficiency of considered energy source.

Thereby, efficiency of the power plant is related only to the process of resource combustion and does not account entire supply chain boundaries. It takes into account only boundaries in the range of power plant and not considers energy losses related to the transportation, extraction and conversion.

Dashed rectangles are representing an example of assessment boundary for the dwelling (Figure 5). Purchased energy is showing amount of FE consumed per hour and E-value is showing amount of PE consumed per hour. Thus energy form coefficient can be described as form of PEF that connects FE with PE.

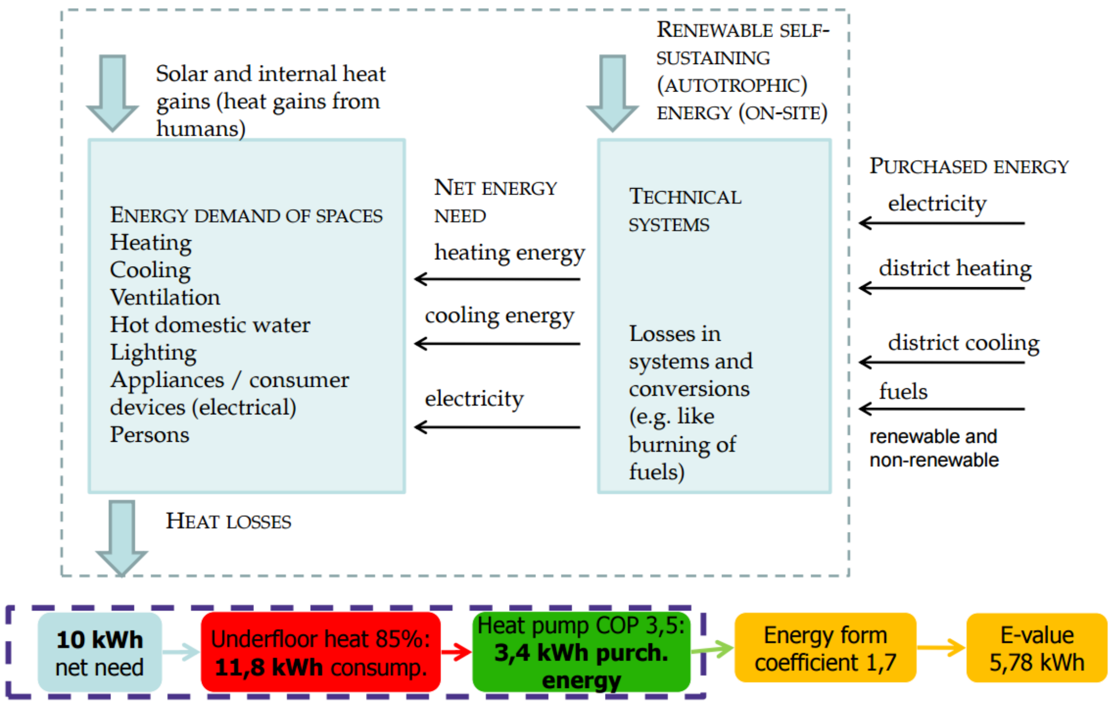


Figure 5. Example of system boundary for delivered energy /18, p. 6/

4.4 Primary energy factor databases.

PEF strongly depends on the country, type of PE source, calculation boundaries and PE calculation options. Thereby due to the lack of available data, it is impossible to calculate PEF for the energy sources. The impossibility of calculation PEF values for the energy sources within this work is the reason why already calculated PEF values from different databases are used instead.

Before calculation of PEF for Finnish electricity and DH by using weighted average method, it is necessary to choose data, which contains information about PEF for different energy sources. NBC D3, IINAS, Ecoheatcool, EN 15603:2008, SAP 2012, prEN ISO/DIS 52000-1:2015 (E) are standards and documents that provide information about PEF of energy sources used for heating and electricity production. PEF of different energy sources is one out of two unknown variables that are needed for Finnish DH and electricity PEF calculations.

Finnish National Building Code D3

In Finland, energy form coefficient for electricity is equal to the 1.7. It means that on the average PE of energy sources used for electricity generation in Finland is 1.7 times higher than FE contained in electricity. Energy form coefficient 0.7 means that presumably energy form coefficient is equal to the non-renewable PEF or renewable PEF. The reason for such conclusion is related to the common sense. Total PEF cannot be lower than 1 because coefficient 1 is related to the energy transfer without any losses and it is evidence of maximum efficiency. Energy form coefficients for electricity and DH have the same meaning as PEF – relation of PE to final energy. Thereby energy form coefficients are regulating purchased energy (FE) and net purchased energy (PE). However, the correctness of that assertion is reviewed after PEF calculations for electricity and DH were done.Table 5 is containing Energy form coefficients for different energy forms.

Table 5. Energy form coefficients /6, p. 8/

Energy form	Energy form coefficient
Electricity	1.7
District heating	0.7
District cooling	0.4
Fossil fuels	1.0
Renewable fuels used in the building	0.5

Draft prEN ISO/DIS 52000-1:2015 (E)

This standard replaces EN 15603:2008 and parts of other EN or EN-ISO standards published in 2007-2008. Standard provides information about PEFs for heating energy sources and electricity. It defines primary energy factors for heating and energy production on non-renewable, renewable and total. Table 6 is containing information about PEF data of heat generation systems.

Table 6. PEF values of different fuels used for heating /16, p. 119/

Type of fuels	Energy carrier	Non-renewable PEF	Renewable PEF	Total PEF
Fossil fuels	Solid	1.1	0	1.1
	Liquid	1.1	0	1.1
	Gaseous	1.1	0	1.1
Bio fuels	Solid	0.2	1	1.2
	Liquid	0.5	1	1.5
	Gaseous	1.1	1	1.4

IINAS

IINAS provides information about non-renewable PEF, renewable PEF and total PEF for heat and electricity production. Information is obtained by using GEMIS. GEMIS evaluates environmental impacts of releasing energy, material and transport systems, i. e. air emissions, greenhouse gases, wastes, and resource use (primary energy, raw materials, land and water) /17, p. 1/.

GEMIS calculates all primary energy inputs of the respective life-cycles, taking into account resource extraction, transport and conversion of energy carriers, the use of fuels in e.g. power plants, heating systems, and the auxiliary energy use as well as materials needed for the construction of all systems involved in the life-cycles to determine the PEF. Table 7 shows PEF data for electricity generation systems.

Table 7. PEF data for electricity generation systems in the EU /17, p. 7/

Energy source	Total PEF	Non-renewable PEF	Renewable PEF
Coal (EU)	2.45	2.44	0.01
Natural gas (average for DE, ES, IT, NL, UK)	1.89	1.89	0.00
Heavy oil (average for DE, ES, IT)	2.76	2.75	0.01
Nuclear (average for DE, FR, UK)	3.50	3.47	0.02
Hydro	1.01	0.01	1.00
Solar (ES, concentrating solar power)	1.03	0.03	1.00
Solar (DE, photovoltaic)	1.25	0.23	1.02
Wind (DE)	1.03	0.03	1.00
Wood (EU, cogeneration)	2.99	0.09	2.90

It is important to notice that PEF for wood is given for cogeneration. Due to the unknown ratio of traditional generation to cogeneration, it is not clear how to take cogeneration share into account yet. Current work is considering two cases. First case neglect cogeneration while second case is taking cogeneration into account.

Table 8 is showing PEF data for heat supply systems.

Table 8. PEF data for heat supply systems in the EU /17, p. 8/

Energy source	Total PEF	Non-renewable PEF	Renewable PEF
Coal	1.79	1.77	0.01
Natural gas	1.34	1.33	0.00
Oil	1.35	1.34	0.01
Wood pellets	1.30	0.11	1.19

EN 15603:2008

EN 15603:2008 provides information about PEF and takes into account energy conversion and transportation losses. That standard contains data about non-renewable PEF, total PEF, heating and electricity generation energy sources. EN 15603:2008 accounts losses from energy transformation and transfer to the energy delivery. /19./ Table 9 is showing PEF data for heating and electricity generation.

Table 9. PEF values of different fuels used for heating and electricity generation /19, p. 37/

Energy source	Non-renewable PEF	Total PEF
Fuel oil	1.35	1.35
Gas	1.36	1.36
Lignite	1.40	1.40
Log	0.09	1.09
Electricity from hydraulic power plant	0.50	1.50
Electricity from nuclear power plant	2.80	2.80
Electricity from coal power plant	4.05	4.05

Ecoheatcool

Ecoheatcool work package 3 provides information about primary resource factor (PRF). Primary resource factor represents energy delivery but excludes the renewable energy component of primary energy. Thereby PRF has the same meaning as non-renewable PEF. Ecoheatcool guidelines are expressing PEF as the ratio of the non-regenerative resource energy required for the building to the final energy supplied to the building. Ecoheatcol accounts all losses from the energy conversion to the energy delivery to the final customers. /20/. Table 10 is providing PRF values for fuels used for heating.

Table 10. PRF values of different fuels used for heating /20, p. 13/

Fuel	Primary resource factor
Lignite coal	1.30
Hard coal	1.20
Oil	1.10
Natural gas	1.10
Renewables (e.g. wood)	0.10

SAP 2012

The Government's Standard Assessment Procedure (SAP) is used for assessing the energy performance of dwellings. It provides net-to-gross conversion factors, total PEF for heating energy sources and ways of calculation PEF. PEF values Primary energy is calculated in the same way as CO2 emission using the primary energy factors in place of the CO2 emission factors /21, p. 36/. Table 11 shows PEF values of different fuels used for heating.

Table 11. PEF values of different fuels used for heating /21, p. 119/

Fuel	Primary energy factor
Anthracite	1.0
Mains gas	1.22
Wood pellets	1.26
Heating oil	1.1

All information about data sources and types of PEF are shown in Table 12. Table 12 is used to sum up information from the Table 5, Table 6, Table 7, Table 8, Table 9, Table 10 and Table 11.

Table 12. Data sources and types of PEF

Type of produced energy	Type of PEF	IINAS	Ecoheatcool Work Package 3	EN 15603:2008	ISO/DIS 52000-1:2015 (E)	SAP 2012	Finnish NBC D3
Heat production	Total PEF	+		+	+	+	
	Non-ren PEF	+	+	+	+		
	Ren PEF	Not accounted in the work					
Electricity production	Total PEF	+		+			
	Non-ren PEF	+		+			
	Ren PEF	Not accounted in the work					
PEF calculation method		Life cycle assessment method				Not mentioned	

4.5 Primary energy factor values

Different PEF values are proposed by various databases. For a more accurate calculations, it is expedient to use assumptions, which are used to fill the missing information. Assumptions in the tables are needed because each database accounts energy sources differently. Assumptions used for PEF calculations are stored in Appendix 1.

PEF values for heat production

Table 13 shows non-renewable PEF values that will be used for calculation of Finnish non-renewable PEF for DH. Table 13 is based on the data presented in Table 8, Table 9, Table 10 and Table 11. Values with assumptions are highlighted. All assumptions made in Table 13 are shown in Appendix 1.

Table 13. Non-renewable PEF values for different energy sources used for heat production

Source	Oil	Hard coal	Natural gas	Peat	Black liquor	Wood fuel	Other fossil	Other renewables	Other energy sources
IINAS	1.34	1.77	1.33	0.11	0.11	0.11	1.77	0.11	1.45
Ecoheatcool	1.10	1.20	1.10	0.1	0.1	0.1	1.2	0.1	1.13
EN 15603:2008	1.35	1.40	1.36	0.09	0.09	0.09	1.40	0.09	1.37
ISO/DIS 52000-1:2015 (E)	1.1	1.1	1.1	0.2	0.5	0.2	1.1	0.2	1.1

Table 14 shows total PEF values that will be used for calculation of Finnish total PEF for DH. Table 14 is based on the data presented in Table 6, Table 8, Table 9 and Table 11. Values with assumptions are highlighted. All assumptions made in the Table 14 are shown in the Appendix 1.

Table 14. Total PEF values of different fuels energy sources used for heat production

Source	Oil	Hard coal	Natural gas	Peat	Black liquor	Wood fuel	Other fossil	Other renewables	Other energy sources
IINAS	1.35	1.79	1.34	1.30	1.30	1.30	1.79	1.30	1.46
EN 15603:2008	1.35	1.40	1.36	1.09	1.09	1.09	1.40	1.09	1.37
ISO/DIS 52000-1:2015 (E)	1.1	1.1	1.1	1.2	1.5	1.2	1.1	1.2	1.1
SAP 2012	1.10	1.00	1.22	1.26	1.26	1.26	1.22	1.26	1.11

PEF values for electricity production

In case of the same energy sources used for electricity generation and heat generation, PEFs for those energy sources are different. EN 15603:2008 is not providing enough information and not used in further work due to insufficient of data. However, it is useful data to give it attention. Table 15 shows non-renewable PEF values for calculation of Finnish non-renewable PEF for electricity network and based on the information provided by Table 7 and Table 9. Values that includes assumptions are highlighted All assumptions made in Table 15 are shown in Appendix 1.

Table 15. Non-renewable PEF values for electricity energy sources

Source	Hydro power	Wind power	Nuclear power	Oil	Hard coal	Natural gas	Solar	Peat	Wood fuel	Other fossil fuels	Other renewables
IINAS	0.01	0.03	3.47	2.75	2.44	1.89	0.23	0.09	0.09	2.75	0.09
EN 15603:2008	0.50		2.80		4.05						

Table 16 shows total PEF values for calculation of Finnish total PEF for electricity network and based on the information provided by Table 7 and Table 9. Values that includes assumptions are highlighted. All assumptions made in Table 16 are shown in Appendix 1.

Table 16. Total PEF values for electricity energy sources

Source	Hydro power	Wind power	Nuclear power	Oil	Hard coal	Natural gas	Solar	Peat	Wood fuel	Other fossil fuels	Other renewables
IINAS	1.01	1.03	3.50	2.76	2.45	1.89	1.25	2.99	2.99	2.76	0.09
EN 15603:2008	1.50		2.80		4.05						

4.6 Relationships between primary energy factors and Eurostat 2020 strategy targets on climate change and energy

Use of PEF in order to express EU 2020 energy strategy headline indicators is the minor aim of the work. Presence of any mathematical relationships between PEF and headline indicators of EU 2020 energy strategy is allowing to characterize PEF as another form of climate control indicator. Confirmation of such relationships shows that PEF can be considered as combination of different energy indicators. The lack of mathematical relationship shows that PEF is a unique parameter and PEF cannot be considered as another form of already used indicators or their combination. That subchapter considers possible relationships between PEF and PE consumption, PEF and FE consumption, PEF and GHGE, PEF and share of renewable energy in gross FE consumption. /22./

Relation between PEF and energy efficiency.

EU energy efficiency calculations are based on the PE consumption and FE consumption values. PE and FE are related to the PEF by Equation 2. Following PEF calculations are not related to the heat or energy production but they are related to the energy efficiency policy in EU. Calculation of the PEF in a country scale is not related to the calculation of PEF for the Finnish electricity or DH production. Those calculations are needed to check how well PEF reflects energy efficiency improvement. According to the Equation 2 total PEFs of the EU and FI are calculated below. /23, 24./

$$\mathrm{PEF}_{1990EU} = \frac{\text{PE consumption}_{1990}}{\text{FE consumption}_{1990}} = \frac{1570MTOE}{1080MTOE} = 1.454$$

$$\mathrm{PEF}_{2005EU} = \frac{\text{PE consumption}_{2005}}{\text{FE consumption}_{2005}} = \frac{1709MTOE}{1186MTOE} = 1.441$$

$$\mathrm{PEF}_{2020aimEU} = \frac{\text{PE consumption}_{2020aim}}{\text{FE consumption}_{2020aim}} = \frac{1483MTOE}{1086MTOE} = 1.366$$

$$\mathrm{PEF}_{1990FI} = \frac{\text{PE consumption}_{1990FI}}{\text{FE consumption}_{1990FI}} = \frac{27.4MTOE}{21.7MTOE} = 1.263$$

$$\mathrm{PEF}_{2005FI} = \frac{\text{PE consumption}_{2005FI}}{\text{FE consumption}_{2005FI}} = \frac{33.4MTOE}{25.2MTOE} = 1.325$$

$$\mathrm{PEF}_{2020aimFI} = \frac{\mathrm{PE\ consumption}_{2020aimFI}}{\mathrm{FE\ consumption}_{2020aimFI}} = \frac{35.9MTOE}{26.7MTOE} = 1.345$$

Figure 6 is used for graphical representation of calculated data. It shows how overall PEF has changed in EU and Finland.

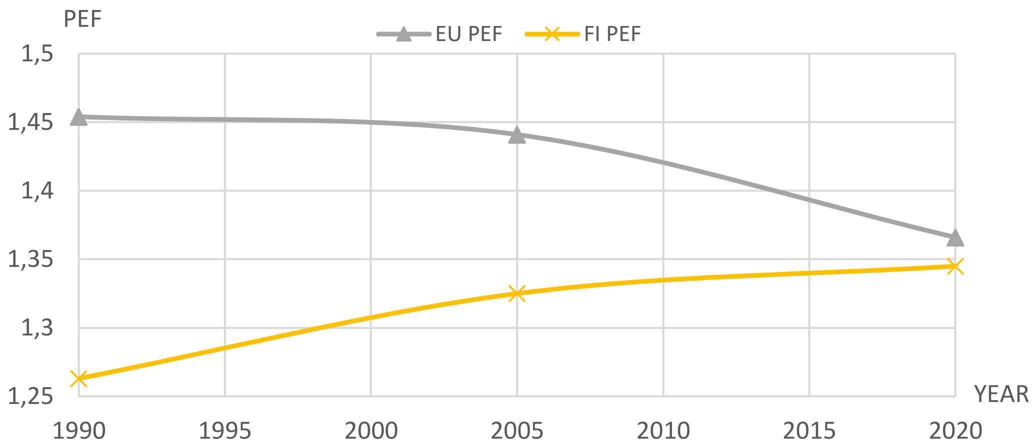


Figure 6 Total PEF for EU and total PEF for Finland by year

Goals of both Finland and EU is to increase energy efficiency by 20% from 1990 till 2020. EU has decreased PEF. Consequently, EU has decreased energy losses. Finland has increased PEF and energy losses. This information contradicts presence of the relationship between energy efficiency and PEF. It shows that decreasing of PEF is not the same as increasing energy efficiency. Thereby there is no direct relationship between PEF and energy efficiency defined by Eurostat. At the same moment of time it is important to notice that Figure 6 is not directly related to electricity PEF and heat generation PEF.

Relationship between PEF and GHGE

Figure 7 is reflecting relationship between nrPEF for heating systems and CO2 emissions. Figure 7 also approves clear linear relation between non-renewable PEF and GHGE. It means that for DH systems and building specific heating systems lower non-renewable PEF is evidence of lower GHGE.

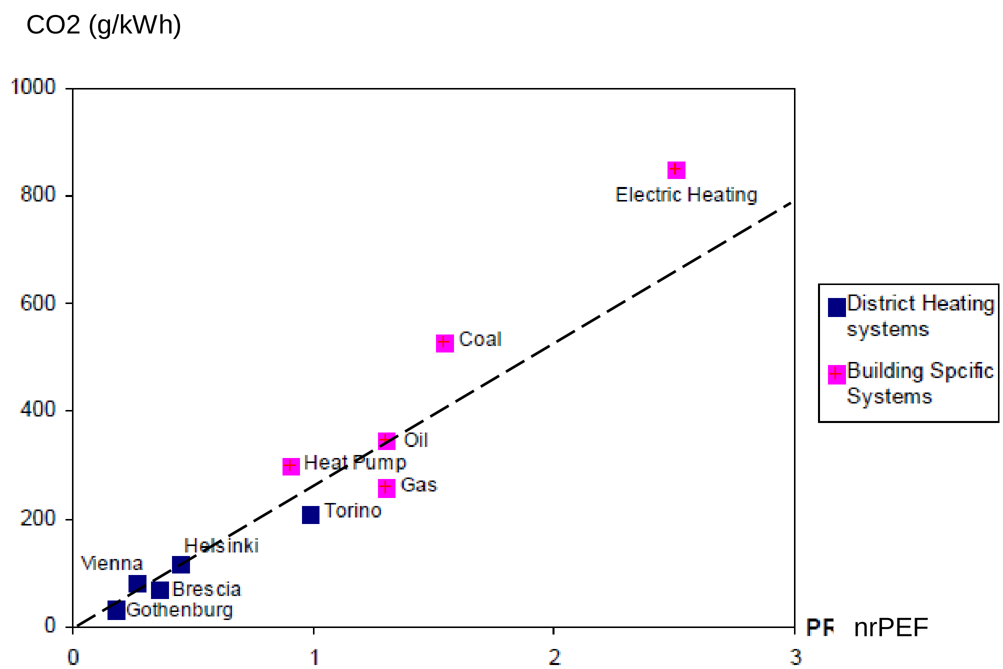


Figure 7. Relationship between non-renewable PEF and CO_2 /20, p. 19/

Figure 8 is showing relationships between total PEFs, non-renewable PEFs for electricity generation and their lifecycle GHGE.

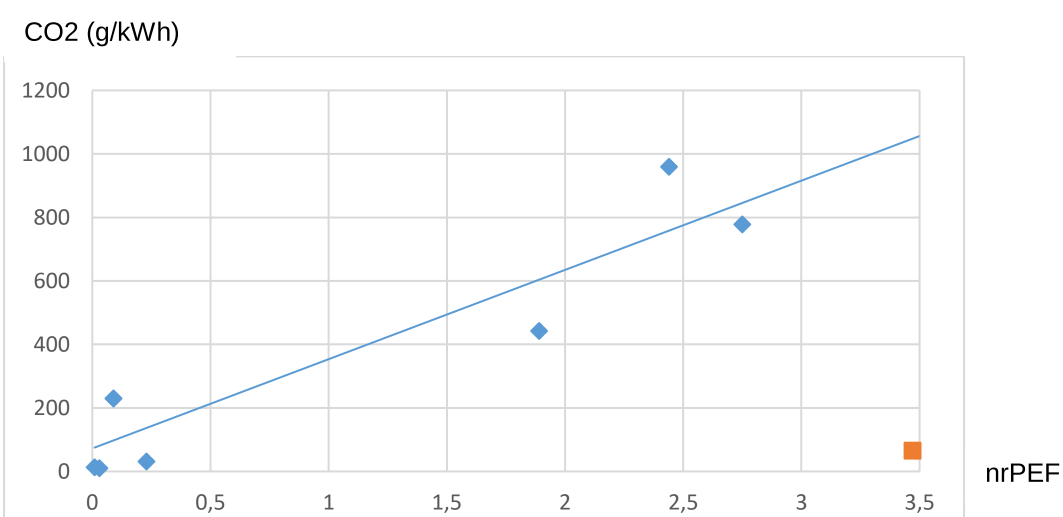


Figure 8. Non-renewable PEF, total values for electricity generation energy sources /25, p. 2950/

In this way, because CO_2 is the main greenhouse gas, non-renewable PEF values have mathematical relationship with all primary energy sources except the nuclear energy. Part of non-renewable non-combustible and renewable non-combustible energy sources used to generate heat in Finland is negligible. Table 17 is used to summarize findings about the relationship between PEF and GHGE.

Table 17. Relationship between lifecycle CO_2 emissions and primary energy sources.

Type of energy	Relationship between non-renewable PEF and lifecycle CO_2 emissions			
	Non-renewable combustible	Renewable combustible	Non-renewable non-combustible	Renewable non-combustible
Heat	+	+	not applied	
Electricity	+	+	-	+

Relationship between PEF and share of renewables

To determine how PEF is related to the share of renewable energy following example has been used. Final energy consumption is 10 MWh, renewables share in final energy production is 10% and all renewable energy is produced by photovoltaic panels located in Denmark. According to Eurostat it means, that 10% out of 10 MWh is so-called green energy. However, this statement is leading to imprecisions. Actual number of renewable energy is calculated by Equation 3 and it is following:

$$Reshare_r = Reshare \cdot FEc \cdot \frac{tPEF - nrPEF}{tPEF} \tag{3}$$

where $Reshare_r$ real share of renewables [%]

$Reshare$ announced share of renewables [%]

FEc final energy consumption [MWh]

$$Reshare_r = Reshare \cdot FEc \cdot \frac{tPEF - nrPEF}{tPEF} = Re\,share \cdot FEc \cdot \frac{rPEF}{tPEF}$$
$$= 10\% \cdot 10MWh \cdot \frac{1.25 - 0.23}{1.25} = 8.16\%$$

There is no 100% clear renewable energy. Renewable energy sources are also containing part of non-renewable energy. In this way accounting of solar, wind, hydro and other renewable energy sources as green energy leads to inaccuracy. Accounting of non-renewable energy sources as fully non-renewable also creates inaccuracy, because those energy sources could contain some renewable energy. Applying non-renewable PEF, renewable PEF and total PEF is a correct way to show an accurate amount of renewables share.

There is no relationship between PEF and share of renewables but combination of PEFs could be used to determine part of the non-renewable energy in renewable energy sources. Thereby applying PEFs is leading to the more accurate accounting of the renewables share in FE consumption. Table 18 shows all relationships between PEF and main climate control indicators.

Table 18. Relationships between PEFs and EU 2020 climate & energy package

Relationship between PEF and energy efficiency	Relationship between PEF and GHGE	Relationship between PEF and RE share in FE consumption
No direct relationship	Direct relationship between non-renewable PEF and renewable combustible, non-renewable combustible, non-renewable non-combustible energy sources	No direct relationship. However, PEFs could be used to improve accuracy of the renewable share in final energy consumption

In this way, despite the fac thatt PEF is regulating energy input and energy output it is not coincides with the Eurostat energy efficiency targets. Eurostat desire to decrease both PE and FE could explain this.

4.7 Share of energy sources in Finnish electricity and DH production.

District heating

District heating is the centralised heating system for large areas such as whole city or group of buildings. An idea of DH system is production of heat in a centralized location with further heat delivery to customers via pipelines. First district heating network appeared in USA in the 1880s and its heating medium was steam. Today steam is replaced by water but principle of DH operation is remaining same. Scheme of modern DH network fueled by biomass is introduced in the Figure 9.

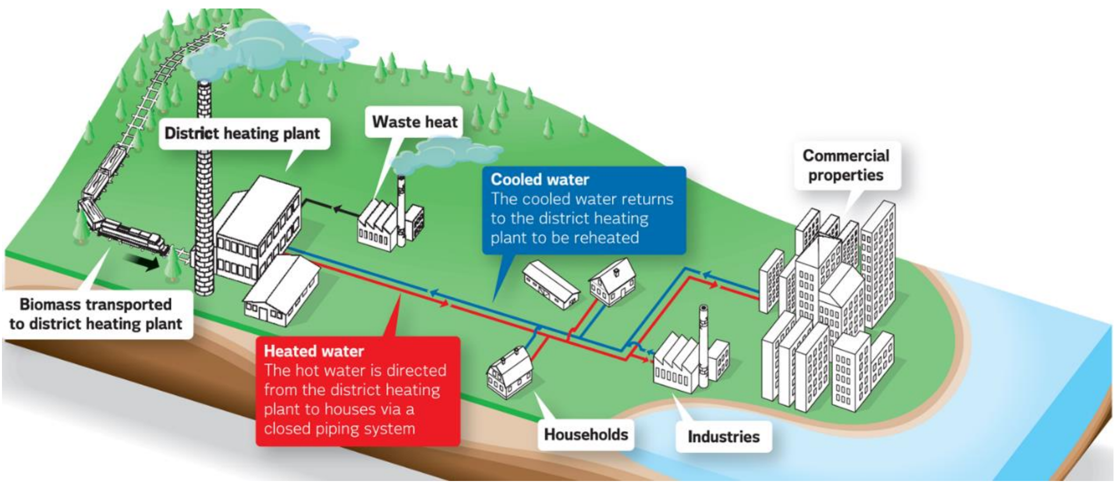


Figure 9. District heating network /26/

District heating in Finland started in the 1950s and now Finland is leading country by share of CHP plants. DH water in Finland is commonly heated up by heat only boilers (HOB) or combined heat and power plants (CHPP). Almost 80% of district heat produced by CHP. One-third of Finnish electricity production obtained by CHP generation. Because of high CHP efficiency such high share of CHP almost provides optimal way to get as low CO_2 emissions as possible to achieve with combustible energy sources.

Major advantage of DH comparing to boilers is less GHGE and much higher conversion efficiency. Main advantages and disadvantages of the DH network are shown in Table 19.

Table 19. Advantages and disadvantages of DH network

Benefits of DH network	Disadvantages of DH network
Using CHP significantly reduce CO_2 emissions per unit of produced energy and greatly improves energy efficiency. Implementation of DH stimulates the economy and creates workplaces. It is cheaper to build one big power plant than install boilers in all potential DH costumer buildings. Operation and maintenance of DH organized more efficiently in comparison with small boiler plants. Cogeneration. Idea of cogeneration is to use waste heat in a power plant for electricity production. Thereby cogeneration power plants are much more energy efficient.	High efficiency can be achieved only during optimal operation range: warm summer and cold winter. Outside of that operation range efficiency significantly reduces. DH Plants designed for certain minimum air temperature. If temperature will drop lower designed temperature then there is need to produce additional heat. Additional heat usually produced by HOB on heavy fuel oil. Additional heat production leads to decreasing efficiency. Heat transfer by the piping systems: heat losses, expensive pipe construction and maintenance.

Figure 10 shows contribution of energy sources to the Finnish district heating network in 2013.

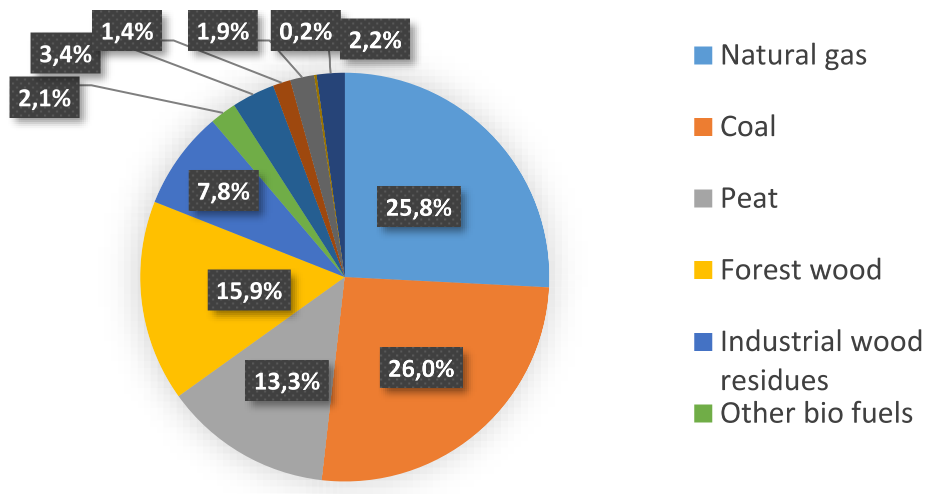


Figure 10. Share of Finnish DH production by source in 2013 /27, p.4/

Overwhelming majority of energy sources used in DH are combustible, because combustion is effective, cheap and simple way to heat up water that is used in DH network. Switching from combustible non-renewable energy sources to combustible renewable energy sources is the main option for further energy efficiency improvement. In Finland around 60% of energy sources are non-renewable combustible and another 40% of energy sources are renewable combustible.

Electricity

Electricity network in Finland is basic service provided to all residents. Finland has electricity transmission links to Sweden, Norway, Russia and Estonia. Electricity in Finland is generated by four hundred power plants and transmitted by the main grid, regional networks and distribution networks. Electricity grid deviation has been done in order to minimize transmission losses. Figure 11 is showing share of electricity generated by energy source in 2014.

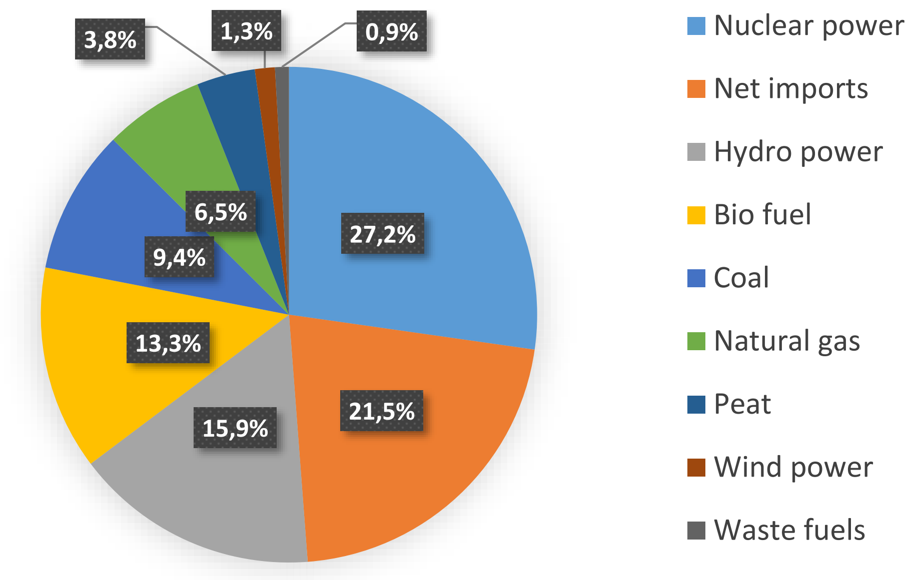


Figure 11. Finnish electricity supply share by energy source in 2014 /28/

Electricity is commonly produced by non-renewable energy sources such as coal, oil, natural gas and renewable energy sources such as water and wind. Near quarter of Finnish electricity generation comes from nuclear power plants. Electricity is generated on conventional condensing power plants, DH CHPP and industrial CHPP.

5 CALCULATION OF THE FINNISH PRIMARY ENERGY FACTORS FOR ELECTRICITY AND DISTRICT HEATING

Idea of the chapter is to calculate PEF for the Finnish DH and Finnish electricity networks. Current chapter is including examples of PEF calculations and results of PEF calculations. Calculations with all its intermediate steps are not included in the work because of inability to represent the entire amount of information.

5.1 Simplified and detailed PEF calculations

Lack of information about PEF values is the reason why energy generated from other energy sources is not taken into account. Both PEF detailed and PEF simplified calculations aren't including energy imports due to the absence of PEF values of imported energy. Simplified PEF calculations are based on the PEF values in Table 15 and Table 16 without any amendments. PEF of electricity production does not depend on PEF of DH production. Figure 12 is used to graphically represent idea of simplified calculation.

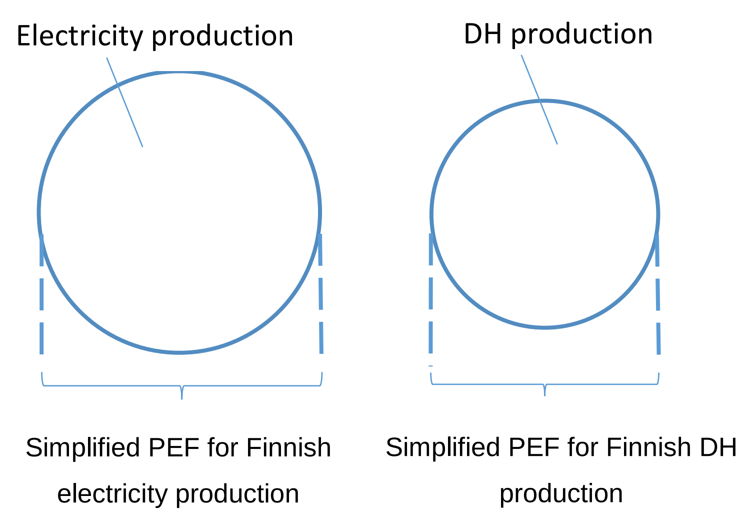


Figure 12. Simplified PEF calculation

It is important to notice that PEF values in Table 15 and Table 16 are not taking cogeneration into account. Almost 80 per cent of Finnish district heat production is based on CHP generation /29/. Ignoring the share of cogeneration leads to an overestimation of the real PEF values. Thereby, in order to increase precision of the calculations, it is necessary to take cogeneration process into account. Figure 13 is showing an idea of the detailed PEF calculation method.

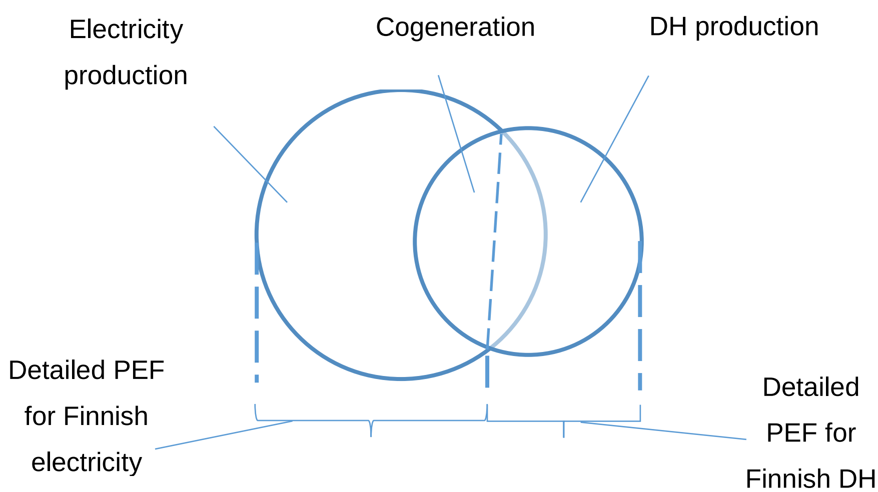


Figure 13. Detailed PEF calculation

5.2 Simplified PEF calculation examples

That subchapter is providing detailed information about PEF calculation method without taking cogeneration into account. Theoretically, it is possible to calculate PEF by ratio between PE and FE for each energy source used for electricity or heat generation. Despite that, due to the lack of information about PE and FE for the energy sources, PEF is calculated by weighted average of already calculated PEF values for different energy sources. Idea of performing PEF calculations is similar to the weighted average method used in chemistry or financial accounting.

Equation 4 is showing how PEF is accounted.

$$\sum_{i=1}^{n} FE_i \times PEF = FE_1 \times PEF_1 + FE_2 \times PEF_2 + \cdots + FE_n \times PEF_n \tag{4}$$

where $\sum_{i=1}^{n} FE_i$ sum of FE produced by energy carriers [MWh]

PEF unknown variable, non-renewable PEF or total PEF, for Finnish electricity or DH [-]

FE_1, FE_2, FE_n amount of FE produced by energy source 1, 2 or n respectively [MWh]

PEF_1, PEF_2, PEF_n PEF for energy source 1, 2 or n respectively [-]

By the same principle it is possible to use PE instead FE for PEF accounting. Eqation 5 is considering that case.

$$\sum_{i=1}^{n} PE_i \times PEF = PE_1 \times PEF_1 + PE_2 \times PEF_2 + \cdots + PE_n \times PEF_n \tag{5}$$

where PE_1, PE_2, PE_n amount of PE produced by energy source 1 , 2 or n repectively [MWh

However, PEF calculated by Equation 5 is not used in the work because its meaning doesn’t meet the goal of the work. Calculations done by Equation 5 dosn’t represent FE and, consequently, they doesn’t represent amount electricity and DH consumed by buildings. That is the reason why Equation 4 is used instead of Equation 5 if it is possible. Equation 4 can be converted into Equation 6 by following steps:

$$PEF = \frac{FE_1}{\sum_{i=1}^{n} FE_i} \times PEF_1 + \frac{FE_2}{\sum_{i=1}^{n} FE_i} \times PEF_2 + \cdots + \frac{FE_n}{\sum_{i=1}^{n} FE_i} \times PEF_n$$

$$PEF = ES_{c1} \times PEF_1 + ES_{c2} \times PEF_2 + \cdots + ES_{cn} \times PEF_n$$

$$PEF = \sum_{i=1}^{n} (ES_{ci} \times PEF_n) \tag{6}$$

where ES_{ci} contribution of the energy source i to the PEF [%

Equation 6 is used to calculate simplified PEF for Finnish electricity and district heat. Data about contribution of the energy source i is taken from Appendix 2.

Example of PEF calculation for Finnish district heating.

An example of PEF calculation for Finnish district heating is based on the initial data for PEF calculation. Table 20 is showing initial data for example of PEF calculation. Table 20 brings together information from Appendix 2, Table 13 and Table 14.

Table 20. Initial data for calculation of the DH PEF in 2015

Oil	Hard coal	Natural gas	Other Foss	Peat	Black liquor	Other wood	Other ren	Other energy sources
Share in 2015, %								
3.2	19.4	16.1	3.3	16.5	0.6	32.4	3.9	NA
Non-renewable PEF values, IINAS								
1.34	1.77	1.33	1.77	0.11	0.11	0.11	0.11	NA
Total PEF values, IINAS								
1.35	1.79	1.34	1.79	1.30	1.30	1.30	1.30	NA

Non-renewable PEF for DH is calculated by Equation 6. Due to the absence of PEF data other energy sources are not taken into account.

$$nrPEF_{DH} = \sum_{i=1}^{n} (ES_{ci} \times nrPEF_n)$$

$$nrPEF_{DH} = \frac{3.2\%}{95.4\%} \times 1.34 + \frac{19.4\%}{95.4\%} \times 1.77 + \frac{16.1\%}{95.4\%} \times 1.33 + \frac{3.3\%}{95.4\%} \times 1.77 +$$
$$+ \frac{16.5\%}{95.4\%} \times 0.11 + \frac{0.6\%}{95.4\%} \times 0.11 + \frac{32.4\%}{95.4\%} \times 0.11 + \frac{3.9\%}{95.4\%} \times 0.11 =$$
$$= 0.045 + 0.36 + 0.224 + 0.061 + 0.019 + 0.001 + 0.037 + 0.004 = 0.752$$

where $nrPEF_{DH}$ non-renewable PEF for Finnish DH [-]

$nrPEF_n$ non-renewable PEF for energy source n [-]

Total PEF for DH is calculated by Equation 6 too. Calculation of the total PEF is identical to the non-renewable PEF.

$$tPEF_{DH} = \sum_{i=1}^{n}(ES_{ci} \times tPEF_{DH})$$

where	$tPEF_{DH}$	total PEF for Finnish DH	[-]
	$tPEF_{n}$	total PEF for energy source n	[-]

Example of simplified PEF calculation for Finnish electricity network.

An example of PEF calculation for Finnish electricity is based on the initial data for PEF calculation. Table 21 is showing initial data for example of PEF calculation. Table 21 brings together information from Appendix 2, Table 15 and Table 16.

Table 21. Initial data for calculation of the electricity PEF in 2015

Hydro power	Wind power	Nuclear power	Oil	Hard coal	Natural gas	Other fossil	Peat	Wood	Other ren	Black liquor	Other energy sources
Share of electricity production in 2015, %											
25.1	3.5	33.7	0.3	7.3	7.7	1.3	4.4	7.1	1	8.2	NA
Non-renewable PEF values, IINAS											
0.01	0.03	3.47	2.75	2.44	1.89	2.75	0.09	0.09	0.09	0.09	NA
Total PEF values, IINAS											
1.01	1.03	3.50	2.76	2.45	1.89	2.76	2.99	2.99	2.99	2.99	NA

Non-renewable PEF for electricity is calculated by Equation 6. Equation 6 is taking into account amendment to DH energy sources share. Due to the absence of PEF data other energy sources and imports are not taken into account.

$$nrPEF_E = \sum_{i=1}^{n} (ES_{ci} \times nrPEF_n)$$

$$nrPEF_E = \frac{25.1\%}{99.6\%} \times 0.01 + \frac{3.5\%}{99.6\%} \times 0.03 + \frac{33.7\%}{99.6\%} \times 3.47 + \frac{0.3\%}{99.6\%} \times 2.75 +$$

$$+ \frac{7.3\%}{99.6\%} \times 2.44 + \frac{7.7\%}{99.6\%} \times 1.89 + \frac{1.3\%}{99.6\%} \times 2.75 + \frac{4.4\%}{99.6\%} \times 0.09 +$$

$$+ \frac{7.1\%}{99.6\%} \times 0.09 + \frac{1\%}{99.6\%} \times 0.09 + \frac{8.2\%}{99.6\%} \times 0.09 =$$

$$= 0.003 + 0.001 + 1.174 + 0.008 + 0.179 + 0.146 +$$

$$+ 0.036 + 0.004 + 0.006 + 0.001 + 0.007 = 1.565$$

where $nrPEF_E$ non-renewable PEF for Finnish electricity [-]

Calculation of total PEF for electricity is identical to the non-renewable PEF for electricity.

5.3 Simplified PEF calculation results

During simplified PEF calculations cogeneration is not taken into account. Therefore amount of cogenerated energy does not affect PEF. PEF calculations are based on six different PEF sources. Five PEF sources for DH and one PEF source for electricity. PEF was calculated for the 2000 – 2015 time interval. All calculations have been done by Equation 6. Results of the non-renewable PEF calculations for the Finnish DH are shown in Table 22.

Table 22. Non-renewable PEF for Finnish DH

Year	Database PEF non-renewable			
	IINAS	Ecoheatcool	EN 15603:2008	ISO/DIS 52000-1:2015 (E)
Initial calculation data	Appendix 2/1			
2000	1.088	0.828	0.990	0.834
2001	1.094	0.829	0.990	0.834
2002	1.074	0.815	0.972	0.820
2003	1.062	0.805	0.960	0.811
2004	1.046	0.797	0.951	0.806
2005	1.033	0.789	0.942	0.800
2006	1.026	0.777	0.925	0.787
2007	1.003	0.763	0.908	0.775
2008	0.979	0.750	0.894	0.766
2009	0.986	0.752	0.896	0.767
2010	0.934	0.716	0.853	0.737
2011	0.894	0.681	0.806	0.703
2012	0.897	0.681	0.805	0.702
2013	0.872	0.656	0.772	0.678
2014	0.826	0.620	0.727	0.646
2015	0.752	0.564	0.658	0.598

Results of the non-renewable PEF calculations for the Finnish DH are shown in Table 23.

Table 23. Total PEF calculation for Finnish DH

Year	Database PEF total			
	IINAS	SAP 2012	EN 15603:2008	ISO/DIS 52000-1:2015 (E)
Initial calculation data	Appendix 2/1			
2000	1.455	1.165	1.290	1.133
2001	1.460	1.161	1.290	1.133
2002	1.456	1.164	1.286	1.133
2003	1.457	1.163	1.283	1.134
2004	1.448	1.169	1.281	1.135
2005	1.443	1.172	1.279	1.134
2006	1.453	1.166	1.276	1.137
2007	1.445	1.170	1.272	1.137
2008	1.432	1.179	1.268	1.137
2009	1.438	1.175	1.269	1.137
2010	1.425	1.182	1.259	1.141
2011	1.429	1.183	1.249	1.145
2012	1.434	1.181	1.249	1.144
2013	1.440	1.182	1.243	1.147
2014	1.436	1.186	1.233	1.149
2015	1.425	1.194	1.218	1.154

Results of total and non-renewable PEF calculations for electricity is shown in Table 24.

Table 24. Non-renewable and total PEF for Finnish electricity network without electricity imports

Year	IINAS	
	Total PEF	Non-renewable PEF
Initial calculation data	Appendix 2/2	
2000	2.495	1.756
2001	2.528	1.780
2002	2.579	1.825
2003	2.583	1.885
2004	2.491	1.735
2005	2.530	1.750
2006	2.567	1.801
2007	2.536	1.731
2008	2.461	1.643
2009	2.549	1.828
2010	2.543	1.749
2011	2.573	1.732
2012	2.490	1.620
2013	2.580	1.761
2014	2.576	1.704
2015	2.466	1.565

Total PEF for DH and electricity is illustrated on Figure 14.

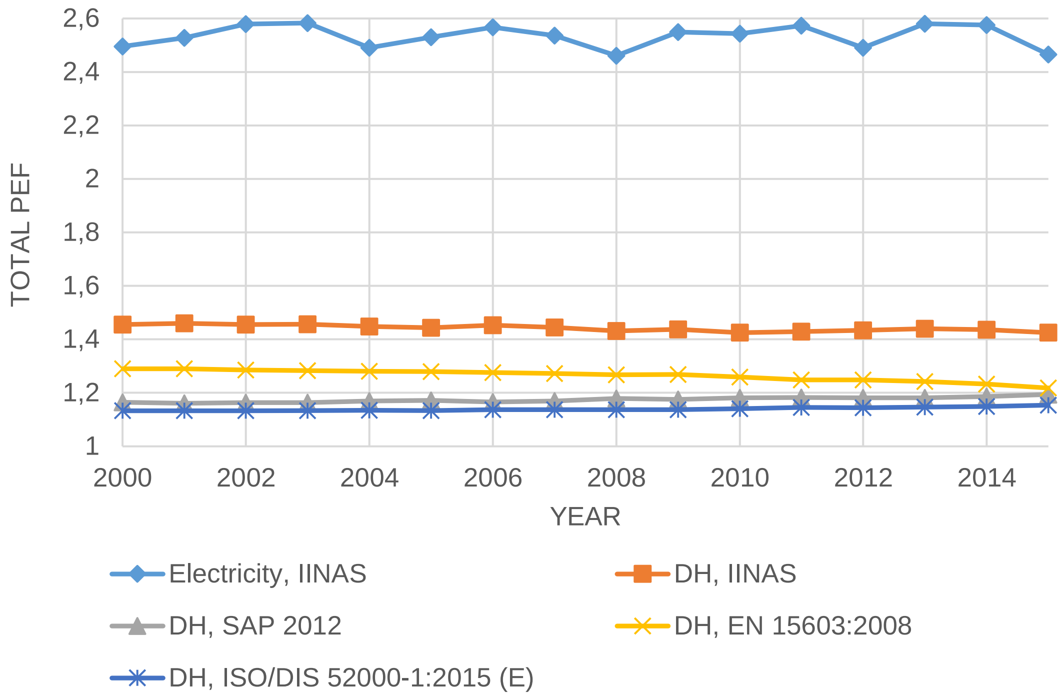


Figure 14. Total PEF for Finnish DH and electricity

Non-renewable PEF for DH and electricity is illustrated on Figure 15.

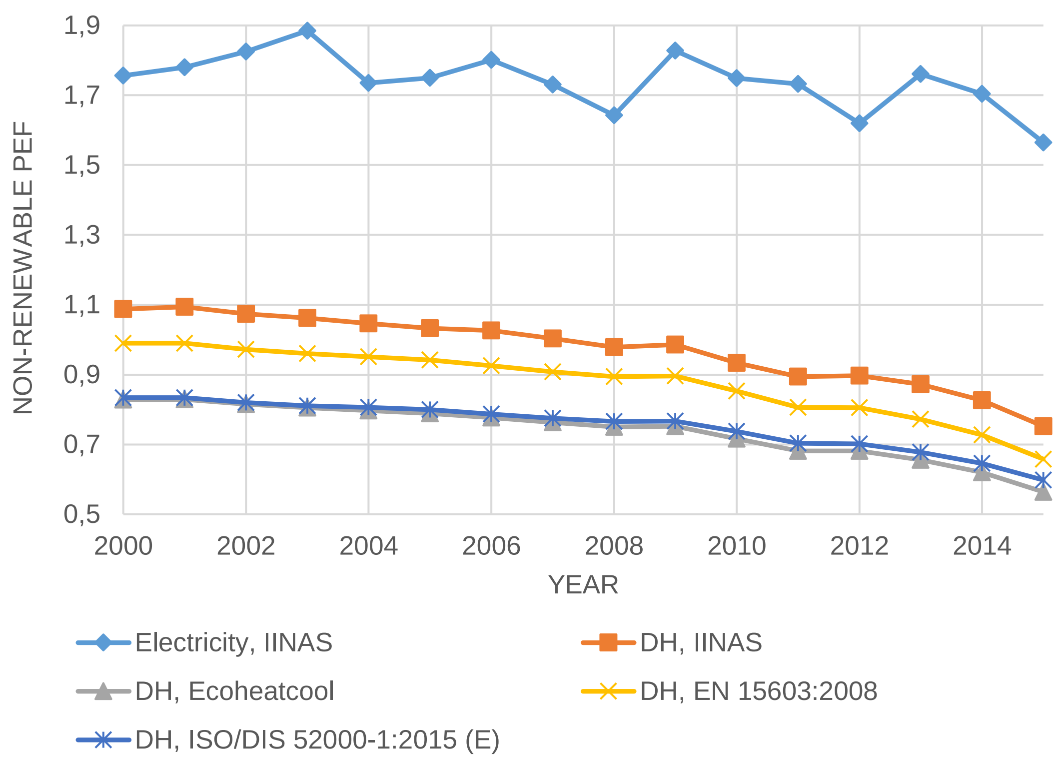


Figure 15. Non-renewable PEF for Finnish DH and electricity

In this way calculated non-renewable PEF values despite the all assumptions and low precision surprisingly match the values introduced in the NBC D3. Non-renewable PEF for electricity in 2012 was 1.62 while NBC D3 energy weighted factor for electricity is 1.7. Non-renewable PEF for DH in 2012 was in range between 0.68 and 0.9 while NBC D3 energy weighted factor for DH is 0.7. Based on the PEF values in 2015 current energy weighted factors used for electricity and DH by NBC D3 became outdated. Also obtained data is indicating equality between non-renewable PEF and NBC D3 energy form coefficient.

Following conclusions can be made according to the Figure 14 and Figure 15. Electricity PEF fluctuations are much higher than DH PEF fluctuations. Total PEFs for electricity and DH are trending to stay constant. According to the PEF drop during 2014-2015 electricity and DH energy form coefficients need yearly revision. It is high possibility that PEF values depend on temperature. Correlating results could be a proof that NBC D3 uses a similar method of calculation. Non-renewable PEF for DH drops faster than non-renewable PEF for electricity. Obtained results also approving assertion about the equality between NBC D3 energy form coefficients and non-renewable PEF made on page 14.

5.4 Detailed PEF calculation

To increase the accuracy of PEF calculation it is necessary to track amount of electrical and heat energy obtained by cogeneration and consider that in PEF calculation. Thereby PEF of electricity and PEF of heat during cogeneration becomes interrelated. Figure 16 is illustrating relation of electricity production to the DH production through CHP DH and also shows how cogeneration brings together heat and electricity production. Figure 16 is based on the values provided in Appendix 3. Electricity net imports are not accounted in the work. In this way, Appendix 3 provides share only about electricity production while Figure 16 takes into account electricity supply and consequently electricity net imports.

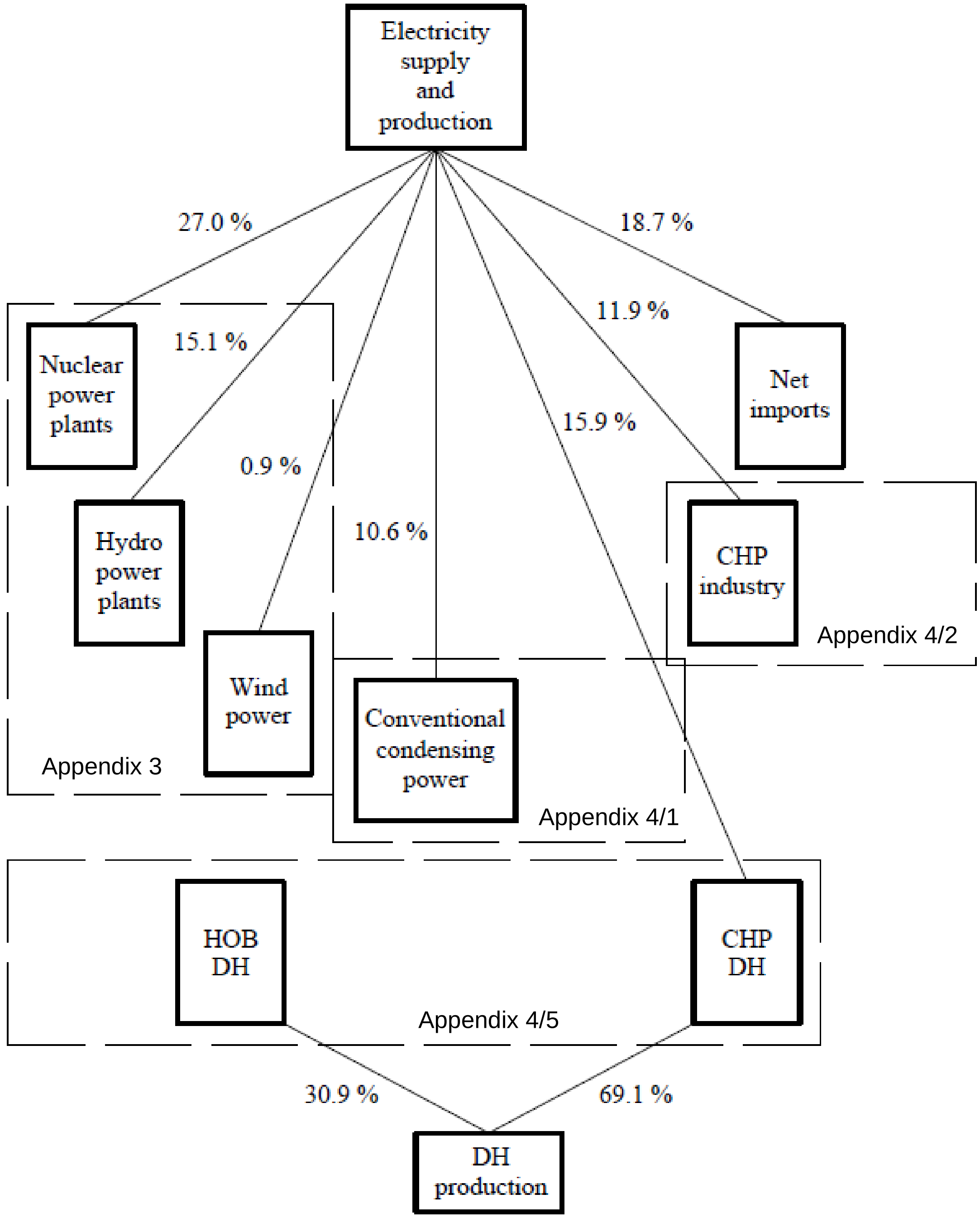


Figure 16. Electricity and heat generation by type in 2013

To take cogeneration into account it is needed to overcome following complexities:

- It is necessary to find out difference in PEF accounting between cogeneration and separate production
- It is necessary to find how DH cogeneration PEF affect electricity cogeneration PEF
- It is needed to determine how PEF values for cogeneration

Main idea used to calculate PEF for cogeneration is to account electricity and heat produced during cogeneration as electricity and heat produced separately. Since PEF is inversely proportional to the efficiency it is possible to account change of the efficiency during switching from cogeneration to conventional generation. Figure 17 is providing information about CHP and separate energy production efficiencies.

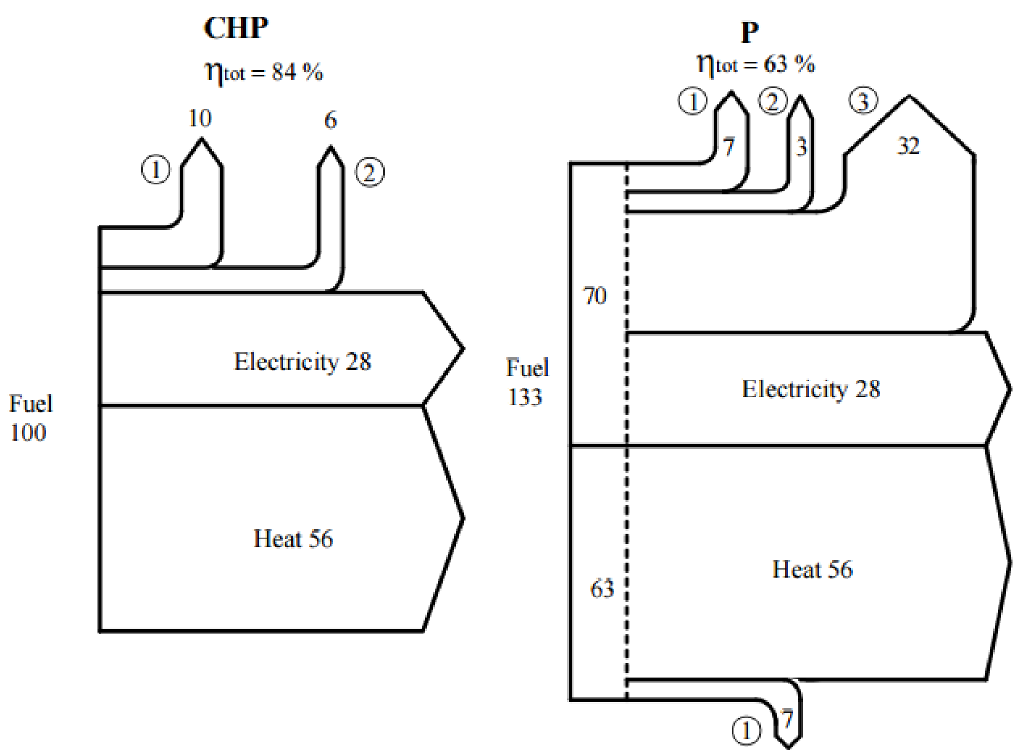


Figure 17. Cogeneration and traditional generation /30/

where	1	Losses in boilers
	2	Losses in electro-mechanical equipment
	3	Losses in condensing;

Equation 7 is used to calculate efficiency of a power plant

$$efficiency = \frac{Fuel\ input}{electricity\ output} \cdot 100\% \qquad (7)$$

where $efficiency$ total efficiency of conventional power plant, HOB or CHPP [%]

According to the Figure 17 and Equation 7 efficiencies of the conventional power plant and HOB are following:

$$efficiency_{CON} = \frac{Fuel\ input}{electricity\ output} = \frac{28}{70} \times 100\% = 40\%$$

$$efficiency_{HOB} = \frac{Fuel\ input}{Heat\ output} = \frac{56}{63} \times 100\% = 89\%$$

Because of co-production of electricity and DH efficiencies are accounted by two boundary cases. Boundary cases are calculated by Equation 7.

1st case: cogenerated Electricity efficiency is 100%

$$efficiency_{CHPe1} = \frac{Fuel\ input}{Heat\ output} = \frac{28}{28} \times 100\% = 100\%$$

$$efficiency_{CHPh1} = \frac{Fuel\ input}{electricity\ output} = \frac{56}{100-28} \times 100\% = 78\%$$

2nd case: cogenerated DH efficiency is 100%

$$efficiency_{CHPh2} = \frac{Fuel\ input}{electricity\ output} = \frac{56}{56} \times 100\% = 100\%$$

$$efficiency_{CHPe2} = \frac{Fuel\ input}{Heat\ output} = \frac{28}{100-56} \times 100\% = 64\%$$

Relationship between DH production efficiency and electricity production efficiency is shown on the Figure 18.

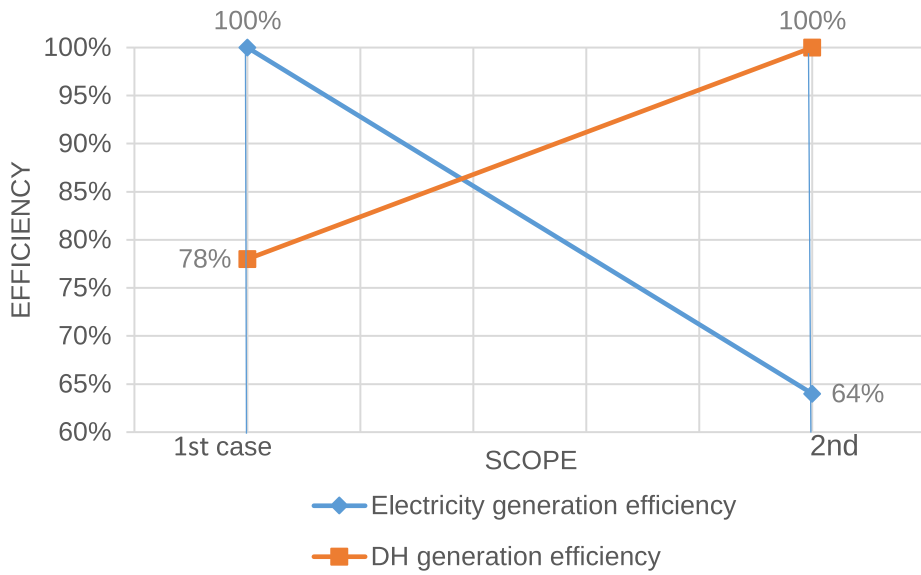


Figure 18. Relationship between the DH generation efficiency and power generation efficiency for cogeneration process

According to the 1st case cogeneration can be presented as separate electricity generation with 100% efficiency and separate DH generation with 78% efficiency. According to the 2nd case cogeneration can be presented as separate electricity generation with 64% and separate DH generation with 100% efficiency.

Due to the fact that calculated efficiency is showing only part of the energy supply chain, which can be represented as PE multiplied by pressure losses during energy transformation:

$$FE = PE \times C_1 \times C_2 \times C_3 \ldots \times C_{n-1} \times C_n \quad (8)$$

where $C_1,\ C_2,\ C_3, \ldots,\ C_n$ coefficients that accounts energy losses during stages $1, 2, 3, \ldots, n$ respectively [-]

Let's assume that C_1 is coefficient that accounts change of the efficiency during switch from cogeneration to the traditional generation. Thereby, taking into account calculations based on Equation 7 coefficients are following:

$$C_{1A} = \frac{efficiency_{HOB}}{efficiency_{CHPh1}} = \frac{89\%}{78\%} = 1.14$$

$$C_{1B} = \frac{efficiency_{HOB}}{efficiency_{CHPh2}} = \frac{89\%}{100\%} = 0.89$$

$$C_{1C} = \frac{efficiency_{CON}}{efficiency_{CHPe1}} = \frac{40\%}{100\%} = 0.4$$

$$C_{1D} = \frac{efficiency_{CON}}{efficiency_{CHPe2}} = \frac{40\%}{64\%} = 0.62$$

Coefficients C_{1A},C_{1B},C_{1C}, C_{1D} for electricity and DH are graphically represented on the Figure 19

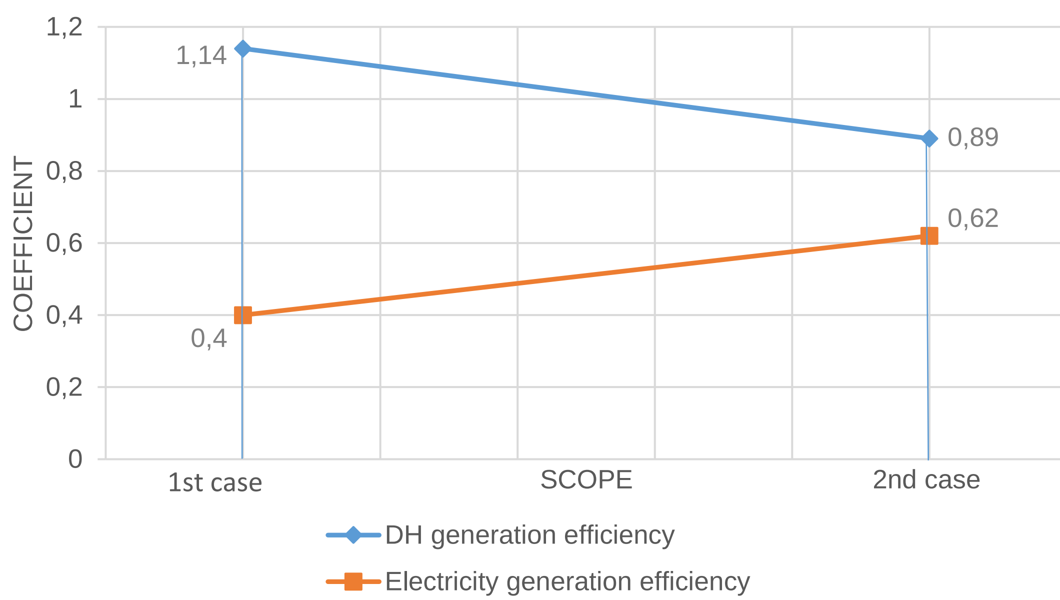


Figure 19. Coefficients used to transfer traditional generation PEF to the cogeneration PEF

Based on the meaning of PEF coefficients C_1 should be applied with taking into account maximum efficiency of non-renewable PEF and total PEF. For total PEF maximum efficiency corresponds to the total PEF equal to 1 (PE fully transformed into FE). For the non-renewable PEF maximum efficiency corresponds to the non-renewable PEF equal to 0 (renewable PEF is equal to the 1, fully renewable energy). Coefficients calculated by Equation 7 should be applied with taking those maximum efficiencies into account.

5.5 Detailed PEF calculation results

Detailed PEF calculations are based on six different PEF sources. Five PEF sources for DH and one PEF source for electricity. PEF was calculated for the 2000 – 2013 time interval. It also takes into account interrelation between cogenerated DH PEF and cogenerated electricity PEF. All calculations have been done by Equation 6. Table 25 is containing PEF calculation results for the Finnish electricity.

Table 25. Total and non-renewable detailed PEFs for the Finnish electricity

Year	Electricity, non-renewable PEF		Electricity, TPEF	
	1st case	2nd case	1st case	2nd case
Initial data / Year	Appendix 5			
2000	1.750	1.674	2.569	2.500
2001	1.774	1.692	2.615	2.541
2002	1.816	1.732	2.664	2.587
2003	1.869	1.795	2.668	2.597
2004	1.723	1.651	2.570	2.501
2005	1.737	1.653	2.620	2.538
2006	1.781	1.709	2.652	2.580
2007	1.713	1.644	2.616	2.546
2008	1.601	1.532	2.541	2.469
2009	1.811	1.731	2.637	2.554
2010	1.719	1.644	2.636	2.552
2011	1.685	1.617	2.663	2.582
2012	1.615	1.549	2.554	2.474
2013	1.722	1.660	2.651	2.572

Table 26 is containing detailed non-renewable PEF calculation results for the Finnish electricity.

Table 26. Detailed non-renewable PEF values for the Finnish DH

	NRPEF							
Year	IINAS		EN15603:2008		ISO/DIS 52000-1:2015		Ecoheatcool	
	1st case	2nd case	1st case	2nd case	1st case	2nd case	1st case	2nd case
Initial data / Year	Appendix 6/1		Appendix 6/2		Appendix 6/3		Appendix 6/4	
2000	0.592	0.770	0.553	0.714	0.466	0.601	0.460	0.595
2001	0.587	0.771	0.548	0.714	0.461	0.599	0.456	0.595
2002	0.570	0.748	0.530	0.691	0.449	0.584	0.442	0.577
2003	0.559	0.739	0.521	0.683	0.442	0.577	0.434	0.570
2004	0.566	0.742	0.532	0.690	0.450	0.584	0.443	0.575
2005	0.561	0.734	0.526	0.683	0.447	0.579	0.438	0.570
2006	0.546	0.720	0.507	0.663	0.432	0.563	0.424	0.554
2007	0.545	0.713	0.509	0.659	0.435	0.562	0.425	0.551
2008	0.537	0.702	0.505	0.654	0.433	0.559	0.421	0.546
2009	0.541	0.709	0.505	0.656	0.431	0.559	0.422	0.548
2010	0.518	0.681	0.485	0.633	0.416	0.543	0.405	0.529
2011	0.490	0.648	0.454	0.595	0.394	0.516	0.381	0.500
2012	0.507	0.653	0.466	0.594	0.405	0.516	0.392	0.501
2013	0.498	0.648	0.453	0.585	0.394	0.508	0.382	0.494

Table 27 is containing detailed PEF calculation results for the Finnish electricity.

Table 27. Detailed total PEF values for the Finnish DH

	TPEF							
Year	IINAS		EN15603:2008		ISO/DIS 52000-1:2015		SAP 2012	
	1st case	2nd case	1st case	2nd case	1st case	2nd case	1st case	2nd case
Initial data / Year	Appendix 6/5		Appendix 6/6		Appendix 6/7		Appendix 6/8	
2000	1.236	1.311	1.160	1.207	1.073	1.093	1.097	1.123
2001	1.233	1.311	1.158	1.207	1.071	1.092	1.093	1.120
2002	1.234	1.309	1.155	1.202	1.073	1.094	1.096	1.123
2003	1.229	1.307	1.152	1.200	1.072	1.094	1.094	1.121
2004	1.229	1.303	1.155	1.202	1.073	1.094	1.097	1.125
2005	1.228	1.302	1.154	1.200	1.073	1.094	1.098	1.126
2006	1.230	1.307	1.150	1.196	1.074	1.096	1.096	1.123
2007	1.230	1.305	1.151	1.195	1.076	1.097	1.101	1.127
2008	1.227	1.299	1.150	1.194	1.077	1.098	1.106	1.133
2009	1.228	1.302	1.149	1.194	1.074	1.096	1.100	1.128
2010	1.221	1.293	1.144	1.189	1.075	1.097	1.101	1.131
2011	1.223	1.296	1.138	1.181	1.078	1.101	1.102	1.132
2012	1.234	1.306	1.142	1.182	1.080	1.102	1.104	1.132
2013	1.236	1.310	1.139	1.180	1.079	1.102	1.104	1.132

Non-renewable PEF for DH and electricity is illustrated in figure 20.

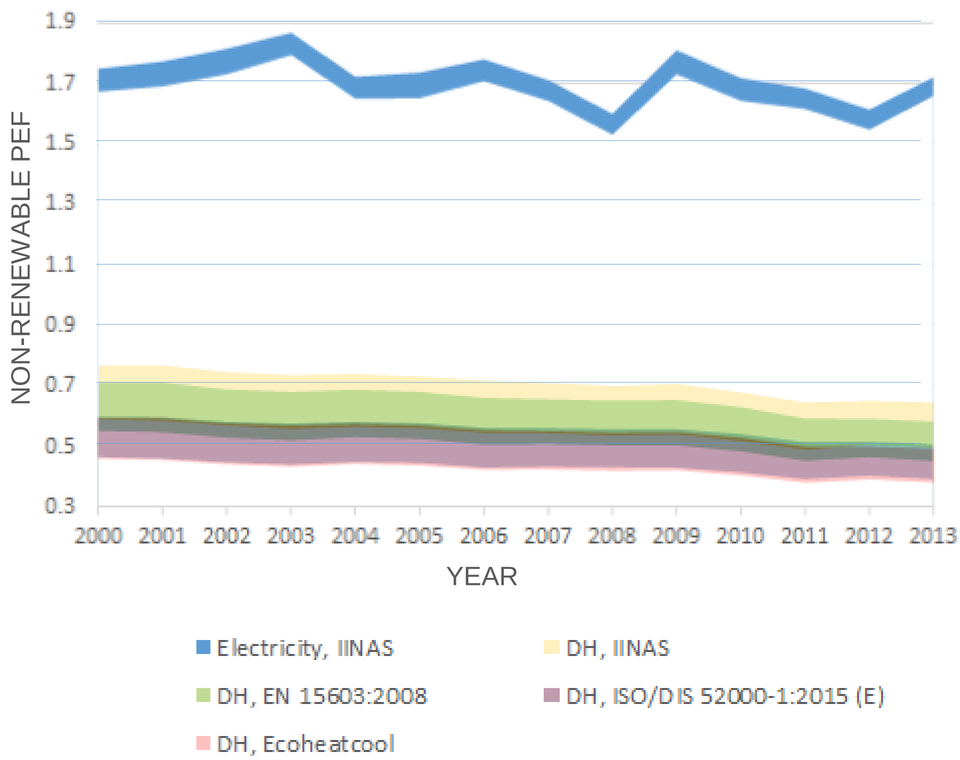


Figure 20. Detailed non-renewable PEF for DH

Detailed non-renewable PEF values match the values of the NBC D3. However, despite the fact cogeneration process was taken into account, difference between non-renewable detailed PEF calculations and NBC D3 is greater than difference between non-renewable simplified PEF calculations and NBC D3. For this reason, there is a question whether the NBC D3 takes cogeneration into account to calculate energy form coefficients. Detailed non-renewable PEF for electricity in 2012 is lying in the range between 1.55 and 1.62. Non-renewable PEF for electricity is close to the NBC D3 electricity energy form coefficient. Detailed non-renewable PEF for DH in 2012 is lying in the range between 0.39 and 0.65. It is much lower than PEF values obtained during the simplified PEF calculations for the DH. Majority of detailed non-renewable PEFs for DH are lower than energy form coefficients provided for DH by NBC D3.

Reason, why non-renewable PEF results aren't corresponding the NBC D3, could be inaccuracies during detailed PEF calculations or disregarding differences between cogeneration and traditional generation by NBC D3. Inaccuracies are following:

First inaccuracy is that efficiency difference between traditional generation and cogeneration is constant and based on figure 17. Figure 17 could contain inaccuracy because relationship between traditional generation and cogeneration doesn't depend on outside temperature. The lack of taking energy source change in consideration also affects accuracy. First inaccuracy is related to the method of cogeneration accounting in the work. Method to express cogeneration by traditional generation multiplied by coefficient is also containing inaccuracy.

Total PEF for DH and electricity is illustrated on figure 21.

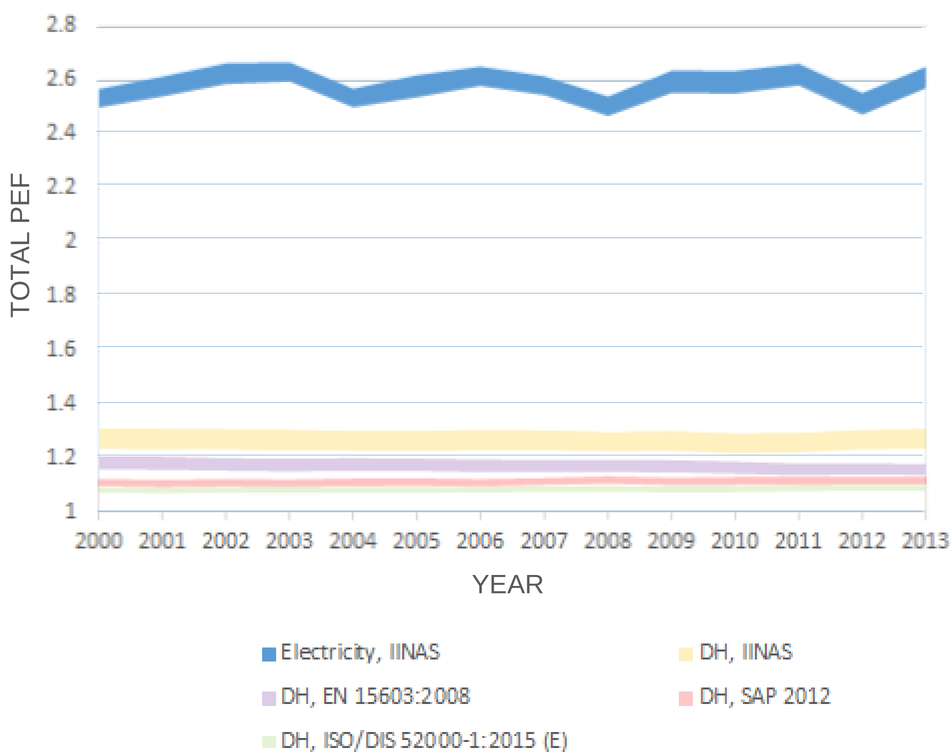


Figure 21. Detailed total PEF for DH

Both total PEF for electricity and total PEF for DH are constant during 2000 – 2013 years. Electricity PEF has much higher fluctuations. Values for the electricity detailed total PEF in 2012 is laying in the range between 2.47 and 2.55. Values for the DH detailed total PEF in 2012 is lying in the range between 1.08 and 1.31.

5.6 PEF trends

To make prediction about Finnish electricity PEF and Finnish DH PEF change in the future it is needed to determine share of energy sources that will be used for electricity and heat production. Prediction is based on the extrapolation of calculated electricity PEF and DH PEF. Extrapolation of the calculated values is giving ability to forecast PEF for Finnish DH network and Finnish electricity network. Finnish DH and electricity PEF forecasts are based on linear extrapolation of calculated PEF values. Trends for Simplified total PEF values for electricity and DH are shown in figure 22.

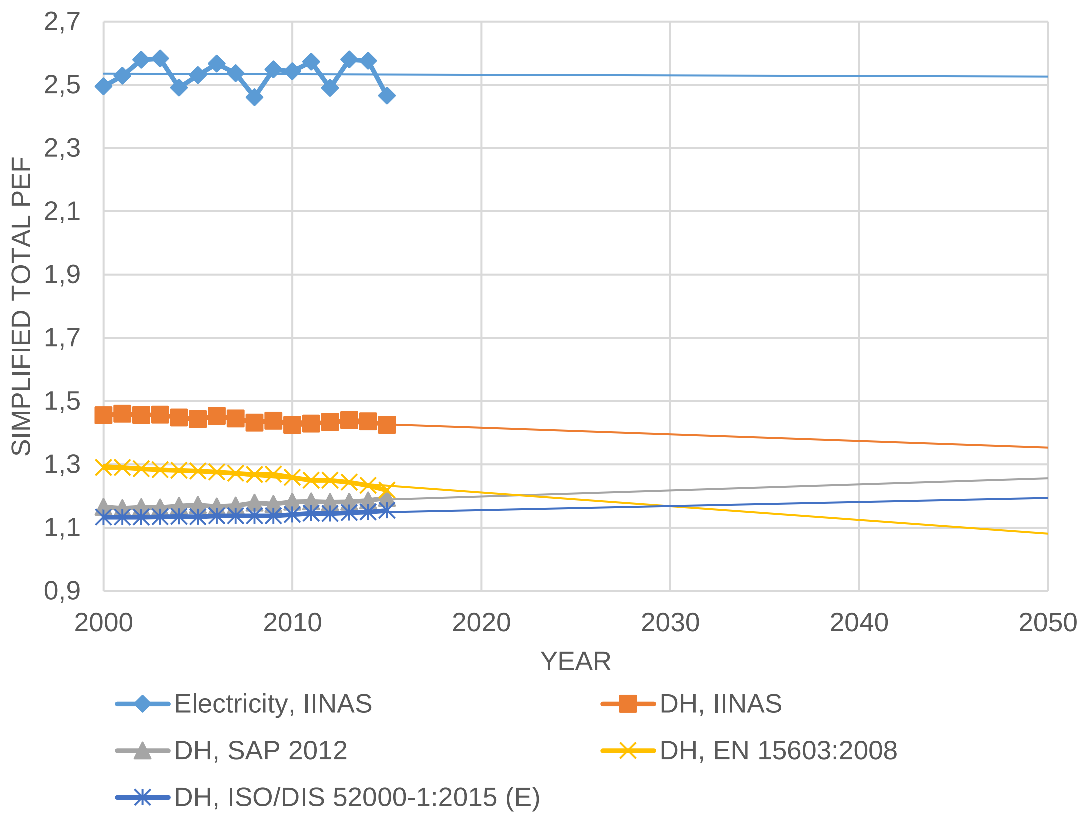


Figure 22. Estimation of simplified total PEF values for electricity and DH

According to the information provided by figure 22 simplified PEFs for both electricity and DH are trending to remain constant or gradually change. Total simplified PEF for electricity is trending to remain constant. Total simplified PEF for DH is trending to minimal changes. According to the extrapolated results, PEF values for the DH will be in the range between 1.08 and 1.36 in 2050. PEF value for electricity will be approximately equal to 2.53 in 2050. Average detailed total PEF values for electricity and DH are shown in Figure 23.

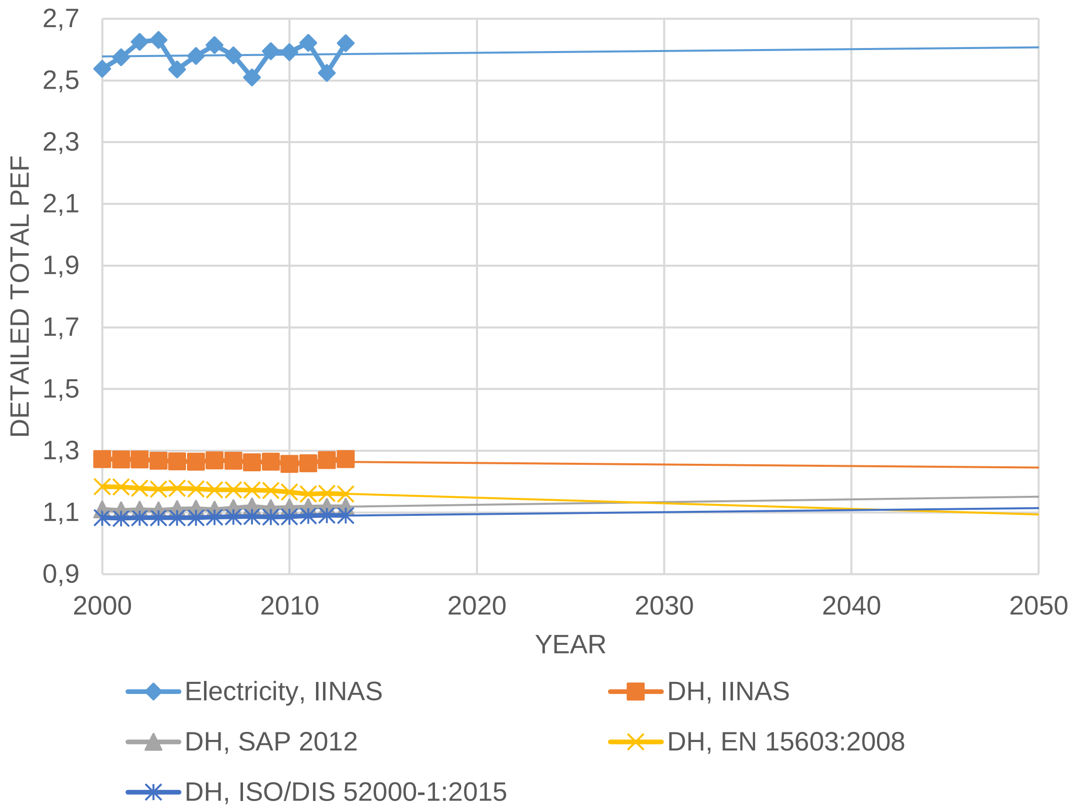


Figure 23. Estimation of average detailed total PEF values for electricity and DH

Difference between detailed total PEF values and simplified total PEF values is minimal. According to the extrapolated results detailed PEF values for the DH will be in the range between 1.09 and 1.27 in 2050. PEF value for electricity will be approximately equal to 2.61.

Simplified non-renewable PEF values for electricity and DH are shown in Figure 24.

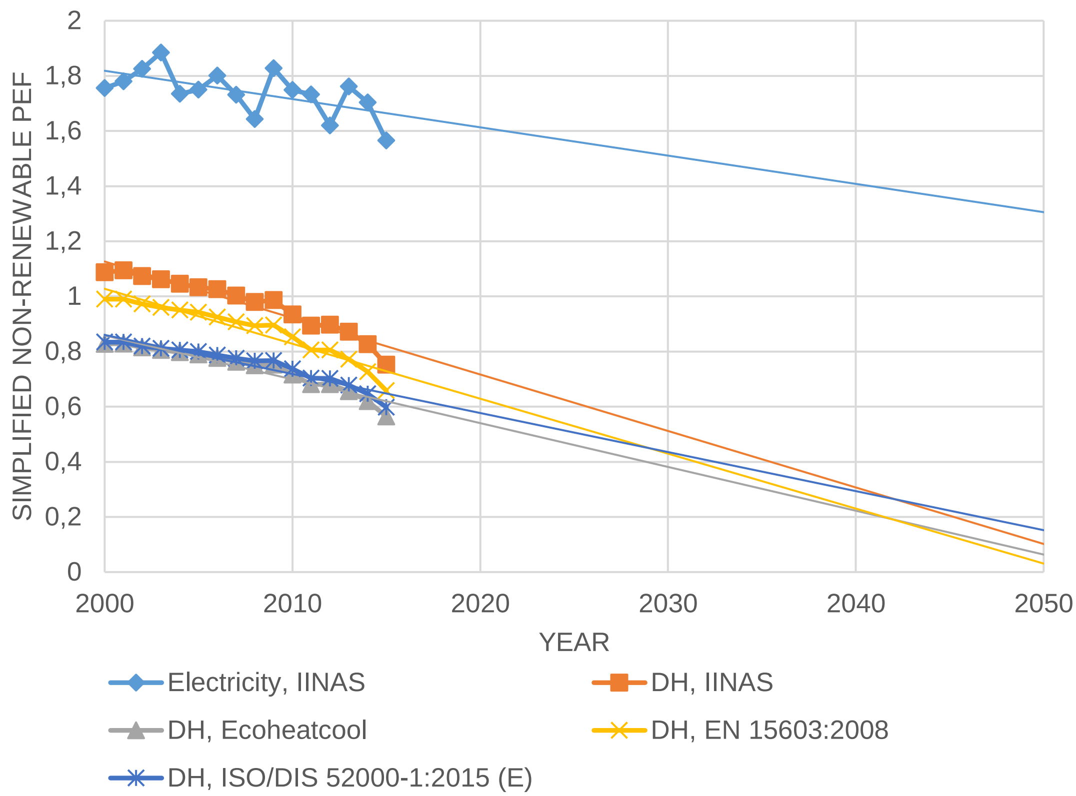


Figure 24. Estimation of simplified non-renewable PEF values for electricity and DH

Both simplified non-renewable PEFs for the electricity and DH are sharply decreasing. With such rapid changes non-renewable PEF for the Finnish DH will lay in a range between 0.04 and 0.16. It means there will be very small share of non-renewable energy. In that case DH is going to be much more ecology friendly than electricity. Electricity PEF is decreasing little bit slowly than DH PEF. It will be equal to the approximately 1.31 in 2050. According to the obtained results energy form coefficients used in the NBC D3 need more frequent revisions.

Average detailed non-renewable PEF values for electricity and DH are shown in Figure 25.

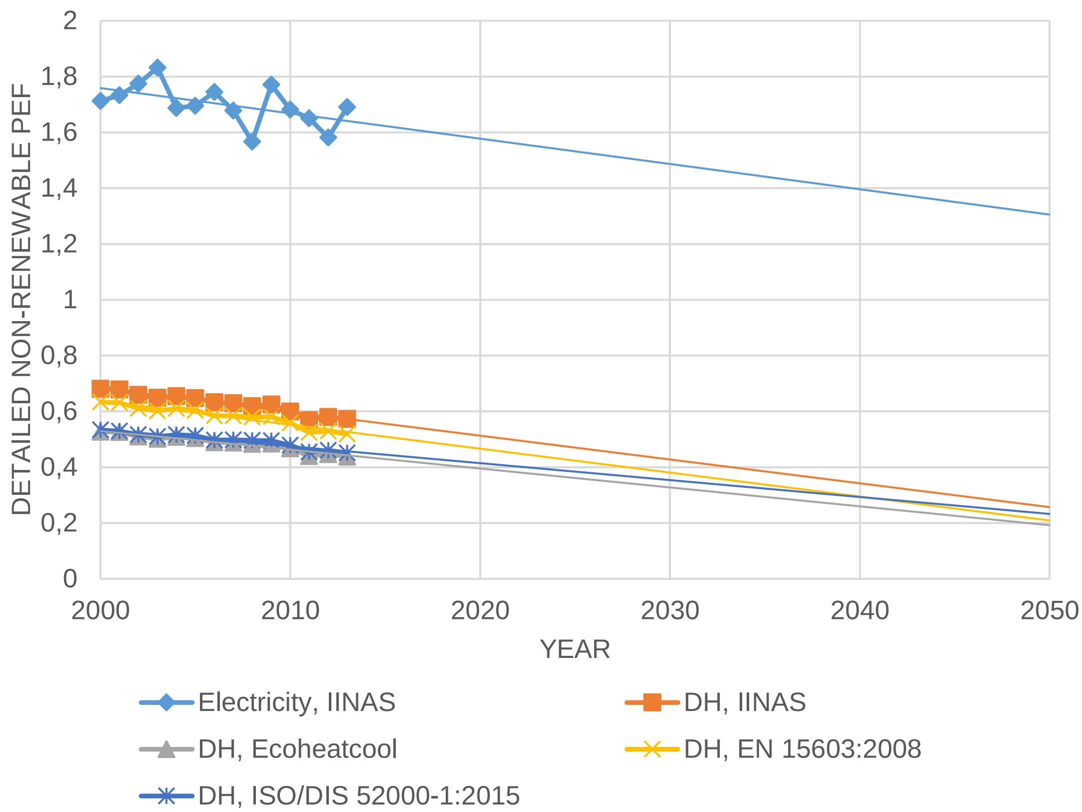


Figure 25. Estimation of average detailed non-renewable PEF values for electricity and DH

Figure 24 is quite similar to the figure 25 except the fact that detailed non-renewable PEF for DH should change slower than simplified non-renewable PEF for DH. Non-renewable PEF for electricity will be approximately equal to the 1.33 in 2050. Detailed non-renewable PEF for the Finnish DH will lay in a range between 0.2 and 0.27 in 2050.

Total PEF for electricity and DH remains constant while non-renewable PEF for both electricity and DH have trends to decrease. Table 28 brings together data from Figure 22, Figure 23, Figure 24 and Figure 25.

Table 28. Finnish PEF forecast 2050.

Database	Total PEF values in 2050		Non-renewable PEF values in 2050	
	Calculation type			
	Simplified	Detailed	Simplified	Detailed
DH, IINAS	1.36	1.27	0.1	0.27
DH, SAP 2012	1.27	1.14		
DH, Ecoheatcool			0.04	0.20
DH, ISO/DIS 52000-1:2015	1.2	1.1	0.16	0.24
DH, EN 15603:2008	1.08	1.09	0.06	0.22
Range for DH PEF	1.08 – 1.36		0.04 – 0.27	
Electricity, IINAS	2.53	2.61	1.31	1.33
Range for electricity PEF	2.53 – 2.61		1.31 – 1.33	

It becomes clear that non-renewable PEF values are decreasing while total PEF values are remaining stable. It means that part of renewable energy is sharply increasing while overall energy losses during DH and electricity generation processes are going to remain approximately at the same level. According to the electricity PEF fluctuations it is recommended to revise energy form coefficient for electricity every year. It is suitable to revise energy form coefficient for DH every two years but in order to gain more precision it is recommended to review them each year.

6 DISCUSSION

Surprisingly, despite the insufficient amount of initial data, obtained PEF calculation results are quite close to the energy form coefficients used by Finnish NBC D3. It was unexpected to gain such precision because there are no instructions on how energy form coefficients should be calculated. On the one hand, it demonstrates the accuracy of the approach based on the weighted arithmetic mean used for PEF calculations, on the other hand it can be a coincidence because of big assumptions amount.

Detection of the dependencies between non-renewable PEF and GHGE for the combustibles energy sources has been expected on the basis of logic. Total, non- renewable and renewable PEFs can successfully replace share of renewables in FE consumption. This step can improve accuracy and give an ability to account part of non-renewable energy used during energy generation from renewable sources. However, absence of the relationship between PEF and Eurostat energy efficiency has been unexpected. Faster reduction of FE comparing to the PE could be a reason for that. In this way, PEF reflects amount of losses during energy transformation from PE to FE while Eurostat reduces both PE and FE which is not an improvement of energy efficiency in the conventional sense.

Energy efficiency indicator used by Eurostat is not reflecting energy efficiency as a relationship between primary consumed energy and final consumed energy. However, it reflects amount of consumed PE and FE instead. Eurostat hasn’t applied any indicators that can describe energy losses for fossil power plants global supply chain, which includes mining, transportation, store and combustion of coal. Missing such data means missing opportunity to monitor sustainability. In that case, the use of PEF can supplement current indicators. However, precise PEF calculation is possible only with sufficient amount of data. Based on the results PEF can be used as a tool to measure sustainability of energy generation.

In this way results of the work support idea that PEF can be used as a tool to account energy performance.

Unexpectedly, simplified PEF calculations met the requirements to a greater extend comparing to the detailed PEF calculations. This can be explained by inaccuracies of the detailed PEF calculation method. One of the possible inaccuracies is usage of figure 17 as foundation for the detailed PEF calculation.

Although the government is trying to increase energy efficiency energy losses during the electricity and heat production are remaining stable without any signs of improvement. Thereby detailed total PEF and simplified total PEF for both electricity and DH are remaining constant. Energy losses during transformation of PE to FE are remaining the same. On the other hand decreasing of non-renewable PEF is evidence of increasing renewable energy share. It leads to the reduction of the energy form coefficient values, applied by Finnish NBC D3. It means that, instead of the reduction of energy losses during electricity and heat production, energy generation plants are becoming friendlier to the environment and rapidly switching to the renewable energy sources.

Another interesting feature to notice is that both total and non-renewable PEFs for electricity are predicted to remain higher than PEFs used to generate DH. This demonstrates the greater DH generation efficiency comparing to the electricity generation. However, rise of the ground source heat pump share caused by its higher efficiency comparing to the DH. Studying the way how ground source heat pump coefficient of performance depends on the PEF of electricity or DH is also important feature to discuss.

In the current work PEF calculation for the Finnish DH and electricity is associated with inaccuracies and assumptions. The lack of accurate data is the reason why margin of error hasn’t been accounted. Mainly, PEF articles are explaining PEF meaning and PEF methodology without making an accent on the PEF calculations. Currently, there is lack of articles related to the PEF calculations. Insufficient amount of precise data is the reason for that. Another possible explanation may be desire to calculate PEF with high precision.

Inaccuracies appears because there is an absence of PEF values for energy sources used in Finland and insufficient amount of databases using life-cycle assessement method.

If electricity market PEF is lower than district heating PEF there will be reason to make a switch from DH to electricity heating. There is almost no possibility that PEF of electricity will be equal to the PEF of district heating. In that situation district heating always will be more effective than heating with electricity. However, ground source heat pumps are the exception. In case of very high share of renewables in electricity production heating with electricity can be alternative to DH. Reason for that is possibility to use non-combustible energy sources for electricity generation while DH is efficient only while using combustible energy sources. However, it is not going to happen in 2050.

The knowledge and information obtained in this study can be used as the foundation for future research works. For example, it is possible to consider how PEF change affects efficiency of the DH and efficiency of the ground source heat pumps. Another possible study could be focused on PEF calculation for the different energy strategies. One more possible research direction could be aimed on the calculation of PEFs for Finnish energy sources.

7 CONCLUSIONS

Finally, PEF for the Finnish DH and electricity have been successfully calculated without any calculation guidelines provided by NBC D3, released in the beginning of 2012. Basically, the obtained non-renewable PEF values coincide with NBC D3 energy form coefficients. On the basis of NBC D3 nowadays energy form coefficient for electricity is 1.7 and energy form coefficient for the DH is 0.7. According to the result of the work in 2015 energy form coefficient was equal to 1.56 and energy form coefficient for the DH was in the range between 0.56 and 0.75.

Forecast of electricity and DH PEF values showed the way how Finnish energy form coefficients are going to change in the future. According to the forecast made in the work 2050 energy form coefficient for electricity will be in the range 1.08 – 1.36, while energy form coefficient for the DH will be in the range 0.04 – 0.27. Based on the fluctuations of calculated data it is recommended to review energy form coefficients for electricity and DH each year.

It is clear that energy form coefficients needed to be revised more often. Weighted coefficients used by NBC D3 are key indicators, which directly affect the process of obtaining building permits and statutory energy performance certificates. On the basis of the work done it can be concluded that values of weighted coefficients used to calculate e-value are outdated.

8 BIBILIOGRAPHY

1. Geohive. 2016. Global population statistics. WWW document. http://www.geohive.com/earth/his_history3.aspx. Updated 17.09.2016. Referred 17.09.2016

2. United Nations Development Programme. 2016. World population prospects. WWW document. https://esa.un.org/unpd/wpp/Graphs/Probabilistic/POP/TOT/. Updated 17.09.2016. Referred 17.09.2016

3. Global Footprint Network. World footprint. 2016. WWW document. http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/. No update information available. Updated 16.09.2016. Referred 16.09.2016

4. Will Steffen, Katherine Richardson, Johan Rockström. Planetary boundaries: Guiding human development on a changing planet. American Association for the Advancement of Science, vol. 347 no. 6223. February 2015. Referred 05.09.2016

5. Gretchen C. Daily, Paul R. Ehrlich. Population, Sustainability, and Earth's Carrying Capacity: A framework for estimating population sizes and lifestyles that could be sustained without undermining future generations. American Institute of Biological Sciences. November 1992. Referred 05.09.2016

6. D3 National Building code of Finland. Energy efficiency of buildings. Regulations and guidelines 2012. Ministry of the Environment, Department of Built Environment. Referred 04.10.2015

7. Green Building Council Finland. 2016. E-Value – calculated consumption based on building characteristics. WWW document. http://figbc.fi/en/building-performance-indicators/calculation-guide/e-value-guide. Updated 17.09.2016. Referred 17.09.2016

8. Educational geography. Shannon River. Retrieved from http://cabinflooresoterica.com/image.php?pic=/images/shannon-river/shannon-river-08.jpg. Referred 17.12.2015

9. Anne Charlotte. Forestry in action. Retrieved from http://www.jjunjucharlotte.com/images/5.jpg. Referred 17.12.2015

10. European Nuclear Society. 2016. Final energy. WWW document. https://www.euronuclear.org/info/encyclopedia/f/finalenergy.htm. Updated 17.09.2016. Referred 17.09.2016

11. Alexander Stoffregen, Oliver Schuller. Primary Energy Demand of Renewable Energy Carriers – Part 1: Definitions, accounting methods and their applications with a focus on electricity and heat from renewable energies. Ecofys. PDF document. April 2014. Referred 23.11.2015

12. Eurostat statistics explained. 2016. Energy saving statistics. WWW document. http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_saving_statistics. Updated 24.02.2016. Referred 24.02.2016

13. Eurostat statistics explained. 2016. Glossary: Primary energy consumption. WWW document. http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Primary_energy_consumption. Updated 11.02.2016. Referred 11.02.2016

14. Alexander Stoffregen, Oliver Schuller. Primary Energy Demand of Renewable Energy Carriers – Part 2: Policy Implications. Ecofys. PDF document. May 2014. Referred 23.11.2015

15. Eurostat statistics explained. 2016. Glossary: Final energy consumption. WWW document. http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Final_energy_consumption. Updated 11.02.2016. Referred 11.02.2016

16. ISO/DIS 52000-1. Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures. International Organization for Standardization. Referred 28.10.2015

17. Uwe R. Fritsche, Hans-Werner Greß. March 2015. Development of the Primary Energy Factor of Electricity Generation in the EU-28 from 2010-2013. IINAS. PDF document. http://www.iinas.org/tl_files/iinas/downloads/GEMIS/2015_PEF_EU-28_Electricity_2010-2013.pdf. Referred 28.09.2015

18. Martti Veuro. Energy efficiency in new buildings in Finland. Mikkeli University of Applied Sciences, 2015. Referred 21.05.2016

19. EN 15603:2008. Energy performance of buildings. Overall energy use and definition of energy ratings. British Standards Institution. Referred 28.09.2015

20. Euroheat & Power. 2006. Ecoheatcool Work package 3 Guidelines for assessing the efficiency of district heating and district cooling systems. PDF document. http://www.euroheat.org/files/filer/ecoheatcool/documents/Ecoheatcool_WP3_Web.pdf. Referred 28.09.2015

21. SAP 2012. The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Building Research Establishment. Referred 17.10.2015

22. Eurostat statistics explained. 2016. Europe 2020 indicators - climate change and energy. WWW document. http://ec.europa.eu/eurostat/statistics-explained/index.php/Europe_2020_indicators_-_climate_change_and_energy. Updated 19.07.2016. Referred 22.07.2016.

23. Eurostat. 2016. Primary energy consumption. WWW document. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=t2020_33&plugin=1. Updated 16.07.2016. Referred 22.07.2016.

24. Eurostat. 2016. Final energy consumption. WWW document. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=t2020_34&plugin=1. Updated 16.07.2016. Referred 18.07.2016.

25. Benjamin K. Sovacool. Valuing the greenhouse gas emissions from nuclear power: A critical survey. Energy Policy, 36, 2940– 2953. 2008. Referred 11.09.2016.

26. Vattenfall. 2013. About district heating. WWW document. https://corporate.vattenfall.com/about-energy/energy-distribution/district-heating/. Updated 01.10.2013. Referred 4.05.2016.

27. Finnish Energy Industries. 2013. District Heating in Finland 2013. PDF document. http://energia.fi/sites/default/files/district_heating_in_finland_2013_web.pdf. No update information available. Referred 04.12.2015

28. Finnish Energy Industries. 2014. Energy year 2014 - Electricity. WWW document. http://energia.fi/en/slides/energy-year-2014-electricity-0. Updated 21.10.2015. Referred 04.12.2015

29. Statistics Finland. 2015. Supply of electricity by energy source. WWW document. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__ehk/220_ehk_tau_220_en.px/?rxid=2c2b4aa8-1134-4ba8-bfed-50d26ee2414d. Updated 15.12.2015. Referred 15.12.2015

30. Jarmo Tuunaen. District Heating. Mikkeli University of Applied Sciences, 2014. Referred 24.05.2016

31. Statistics Finland. 2016. District heat production. WWW document. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__salatuo/040_salatuo_tau_104.px. Updated 11.02.2016. Referred 04.05.2016

32. Statistics Finland. 2016. Production and total consumption of electricity. WWW document. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__salatuo/030_salatuo_tau_103.px. Updated 12.07.2014. Referred 04.12.2015

33. Statistics Finland. 2016. Electricity supply and production. WWW document. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__salatuo/010_salatuo_tau_101.px Updated 11.02.2016. Referred 06.05.2016

34. Statistics Finland. 2016. Heat and power production and energy sources. WWW document. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__ehk/130_ehk_tau_113_en.px/?rxid=2c2b4aa8-1134-4ba8-bfed-50d26ee2414d. Updated 11.09.2016. Referred 11.09.2016

35. E. Molenbroek, E. Stricker, T. Boermans. ECOFYS. PE factors for electricity in buildings Toward a flexible electricity supply. PDF document. http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/pef-finalreport.pdf. Referred 28.09.2015

Appendix 1/1

List of assumptions for the Primary Energy Factor values

Table 28. Assumptions for the Table 21 and Table 22

<table>
<tr><th></th><th>IIINAS</th><th>EN 15603:2008</th><th>ISO/DIS 52000-1:2015 (E)</th><th>SAP 2012</th></tr>
<tr><td rowspan="3">Assumptions</td><td colspan="4">1. PEF of the other energy sources is calculated as average between coal, gas and oil PEF
2. PEF of the other fossil energy sources is equal to the fossil energy source with highest PEF
3. If PEF for peat or black liquor is not given then it accounted as equal to the PEF of wood.
4. PEF of other renewables is equal to the wood fuel PEF</td></tr>
<tr><td>PEF of Hard coal is equal to the coal PEF</td><td rowspan="2">Timber PEF is equal to the wood PEF</td><td>Peat is accounted as solid biofuel</td><td>PEF of the Natural gas is equal to the PEF of gas and other fossil</td></tr>
<tr><td>PEF of wood pellets is equal to the PEF of wood fuel</td><td>Black liquor is accounted as liquid biofuel</td><td>Non-renewable PEF and total PEF values for different fuels are used for heating</td></tr>
</table>

Appendix 1/2

List of assumptions for the Primary Energy Factor values

Table 29. Assumptions for the Table 15 and Table 16

	IINAS	EN 15603:2008
Assumptions	1. PEF value for nuclear power accounted as average PEF for Denmark, France and UK 2. PEF value of the Wind power is equal to the PEF of German wind park 3. Heavy oil PEF is equal to the average oil PEF between Denmark, Spain and Italy. 4. Natural gas PEF is equal to the average natural gas PEF between Denmark, Spain, Italy, Netherlands and UK. 5. Coal PEF is equal to EU hard coal PEF 6. Peat PEF is equal to wood fuel PEF 7. Other renewables PEF is equal to wood fuel PEF, other fossil fuels PEF is equal to oil PEF.	-

Appendix 2/1

Share of the energy sources used for district heat and electricity production

Table 30. District heat production share by source /31/

Energy source	Oil	Hard coal	Natural gas	Other Foss	Peat	Black liquor	Other wood	Other ren	Other energy sources
Year	Share, %								
2000	6.4	26.3	34.6	1.1	17.5	1.3	9.7	0.8	2.3
2001	7.5	27.6	32.6	1.2	18.3	1.2	9.2	0.8	1.6
2002	6.9	26.8	32.5	1.2	18.9	0.8	10.4	0.7	1.7
2003	7.5	27.2	30.7	0.9	19.4	0.8	10.6	0.9	2.1
2004	6.2	25.2	33.3	1	18.5	0.9	11.8	1.1	2
2005	5.8	24.1	34.1	1.1	17	0.8	13.3	1.9	2
2006	6.9	26.7	29.3	0.9	18.5	1.1	13.5	1.4	1.9
2007	6.9	24.9	29.6	0.9	21.3	0.6	12.1	1.6	2.1
2008	5.4	21.5	32.2	1.4	18.6	0.6	14.9	2	3.4
2009	7.4	22.7	29.6	1.6	17.7	0.6	16.2	1.9	2.3
2010	6.9	20.3	29.4	1.4	19.4	0.6	18.3	1.3	2.4
2011	5.2	21.4	26.1	1.6	19.1	0.5	22.3	1.3	2.4
2012	5.5	22.1	24.7	1.9	16.3	0.5	24.7	1.8	2.5
2013	3.3	23.4	22.6	2.1	14.5	0.6	28.3	2.3	2.9
2014	3.2	22.2	19.6	2.8	15.2	0.6	30.1	3.1	3.3
2015	3.2	19.4	16.1	3.3	16.5	0.6	32.4	3.9	4.6

Appendix 2/2

Share of the energy sources used for district heat and electricity production

Table 31. Production of electricity by energy source /32/

Energy source	Hydro power	Wind power	Nuclear power	Oil	Hard coal	Natural gas	Other fossil	Peat	Wood	Other ren	Black liquor	Other energy sources
Year	Share, %											
2000	21.5	0.1	32.1	0.8	11.9	14.6	1.1	5.5	4.3	0.2	7.6	0.4
2001	18.3	0.1	30.7	0.9	14	15.7	1	8.1	4	0.2	6.7	0.3
2002	14.8	0.1	29.9	1.2	16.5	15.7	1	8.6	4.4	0.2	7.2	0.4
2003	11.8	0.1	27.2	1.1	22.3	16.7	0.9	8.5	4.2	0.3	6.5	0.4
2004	18.1	0.1	26.5	0.7	18.8	15.1	0.8	7.4	4.6	0.3	7	0.4
2005	19.8	0.2	33	0.7	9	16.1	1.2	6.2	5.4	0.4	7.5	0.5
2006	14.4	0.2	28	0.6	19.3	15.2	1	7.9	5.2	0.3	7.5	0.5
2007	18	0.2	28.9	0.6	16.7	13.2	1	8.9	4.4	0.4	7.3	0.4
2008	22.7	0.3	29.6	0.8	10.7	14.4	1	6.5	5.6	0.5	7.1	0.7
2009	18.2	0.4	32.6	0.7	15	13.8	0.8	6	5.2	0.5	6.2	0.5
2010	16.5	0.4	28.3	0.6	17.6	14.2	0.9	7.6	6	0.6	6.9	0.5
2011	17.4	0.7	31.6	0.5	13	13.1	0.9	7.2	7.2	0.6	7.2	0.6
2012	24.6	0.7	32.6	0.4	9.8	9.7	0.9	5.1	7.4	0.7	7.5	0.6
2013	18.5	1.1	33.2	0.3	14.6	9.7	1	4.3	7.8	0.8	8	0.6
2014	20.2	1.7	34.6	0.3	11.4	8.2	1	4.9	7.9	0.9	8.2	0.6
2015	25.1	3.5	33.7	0.3	7.3	7.7	1.3	4.4	7.1	1	8.2	0.5

Appendix 3
Electricity supply share by energy generation type

Table 32. Electricity production share by energy generation type /33/

	Hydro power	Wind power	Nuclear power	Conventional condensing power	CHP, industry	CHP, district heat
Data				Appendix 4/1	Appendix 4/2	Appendix 4/3, Appendix 4/6
	Share, %					
2000	21.5	0.1	32.1	10.3	16.1	19.9
2001	18.3	0.1	30.7	15.1	14.8	21
2002	14.8	0.1	29.9	17.3	16	21.9
2003	11.8	0.1	27.2	26.7	14.3	19.9
2004	18.1	0.1	26.5	21.2	14.4	19.7
2005	19.8	0.2	33	7.9	15.9	23.1
2006	14.4	0.2	28	22.4	15.3	19.8
2007	18	0.2	28.9	18.5	15	19.4
2008	22.7	0.3	29.6	11.8	15	20.5
2009	18.2	0.4	32.7	13	13.1	22.8
2010	16.5	0.4	28.4	18.4	13.5	22.9
2011	17.4	0.7	31.6	14	14.4	21.9
2012	24.6	0.7	32.6	7.6	13.1	21.3
2013	18.5	1.1	33.2	13	13.4	20.8
2014	20.2	1.7	34.6	9.7	13.3	20.4

Appendix 4/1

Share of the energy sources used for certain energy generation type

Table 33. Conventional condensing power electricity production by energy source /34/

Year	Oil	Hard coal	Natural gas	Other Foss	Peat	Other wood	Other renewables	Other energy sources
	TJ							
2000	1081	39283	3697	6460	9796	6205	95	978
2001	1921	52732	7277	6054	26831	8717	310	849
2002	3029	69902	7335	5421	25244	7943	284	1310
2003	4575	125994	22751	7613	31790	12748	415	2657
2004	1697	106495	11937	7102	27331	13024	596	2750
2005	1455	20417	2482	7506	12013	11337	609	2413
2006	1713	100398	15989	7900	27896	15560	566	2576
2007	1628	78766	4586	8200	30281	10333	795	2816
2008	1521	37931	3477	7746	18086	14911	977	3133
2009	1991	56181	1537	4972	11724	8042	859	1894
2010	1332	85403	2024	6044	23457	15085	1505	2140
2011	1361	47992	1824	5974	20807	18587	1797	2108
2012	1375	24615	1111	4887	7322	12381	1126	1691
2013	1161	54988	1363	4563	7751	14865	1311	1804

Appendix 4/2

Share of the energy sources used for certain energy generation type

Table 34. CHP industry electricity production by energy source /34/

Year	Oil	Hard coal	Natural gas	Other Foss	Peat	Other wood	Other renewables	Other energy sources
	TJ							
2000	10742	8979	42172	2164	19921	180155	1376	4273
2001	10886	7626	44120	2537	21832	165396	1649	4377
2002	10858	7429	41818	3080	24403	180024	1576	4920
2003	9040	7191	42169	3294	25257	178253	1989	4750
2004	10092	7321	41893	3580	21008	189809	1989	5469
2005	9054	7063	39868	3108	19129	170821	2290	4636
2006	8132	6883	42535	2383	24305	195367	2255	5860
2007	8870	6420	39581	2721	25069	190632	2701	4591
2008	7459	5903	37783	2435	22593	180930	2729	5799
2009	5951	4929	33110	3253	19168	145155	3009	4933
2010	6924	4945	35078	3409	22414	170969	2835	5264
2011	6992	4211	34441	2958	20353	170419	3002	6872
2012	6055	4048	28752	3374	16434	173897	4073	6890
2013	4481	2704	23520	3313	14457	178952	3400	6924

Appendix 4/3

Share of the energy sources used for certain energy generation type

Table 35. CHP DH electricity and heat production by energy source /34/

Year	Oil	Hard coal	Natural gas	Other Foss	Peat	Other wood	Other renewables	Other energy sources (NA)	∑
	TJ								
2000	2573	43897	57637	1532	26918	15516	616	494	148689
2001	3019	51984	64369	1813	32463	15591	864	641	170103
2002	3049	51452	65085	1839	34913	17067	821	563	174226
2003	2729	54604	64889	1814	36500	17786	1096	613	179418
2004	2065	50417	68416	2051	34261	19971	1511	632	178692
2005	1622	46890	66713	2126	30963	21812	1894	774	172020
2006	1414	53758	58817	1871	33982	22953	1357	723	174152
2007	1526	50697	57870	1839	37945	18807	1706	885	170390
2008	1600	44610	63905	1416	32381	22833	1845	2306	168590
2009	2111	49339	61344	1890	32880	26975	2259	1381	176798
2010	1832	47851	71824	1695	38945	33499	2199	1260	197845
2011	1032	45273	56052	2151	33373	35652	1974	1206	175507
2012	777	47911	43529	3229	31431	42217	3304	1256	172398
2013	689	48864	42263	4724	25662	44818	4573	1874	171593

Table 36. Separate heat production by energy source /34/

Year	Oil	Hard coal	Natural gas	Other Foss	Peat	Other wood	Other ren	Other energy sources (NA)	∑
	TJ								
2000	19343	2807	13882	1956	4508	12256	826	9593	55578
2001	22389	2398	13297	2066	3425	13089	754	8882	57418
2002	20994	3027	13480	2230	5354	15133	896	8781	61114
2003	21718	2460	13348	930	5730	14493	825	11243	59504
2004	22193	2679	16129	901	5400	14803	979	11660	63084
2005	21050	2765	15167	894	5512	13993	1673	12082	61054
2006	19948	2472	14116	746	5049	15872	1536	11790	59739
2007	19954	2124	16002	947	6982	16146	1503	12556	63658
2008	17660	1584	17158	1893	6653	18053	2069	12227	65070
2009	19453	2096	15574	1957	6608	14494	1741	9277	61923
2010	19116	2847	16231	1904	7272	15658	1220	10653	64248
2011	15544	2685	12206	1560	6465	18685	1085	10138	58230
2012	14511	5021	18422	1129	6387	19257	1283	9630	66010
2013	11158	5783	16777	1114	5419	20582	1773	8977	62606

Appendix 4/5

Share of the energy sources used for certain energy generation type

Table 37. Separate heat production by energy source /34/

Year	Separate heat production		CHP DH	
	TJ	%	TJ	%
2000	55578	27.2%	148689	72.8%
2001	57418	25.2%	170103	74.8%
2002	61114	26.0%	174226	74.0%
2003	59504	24.9%	179418	75.1%
2004	63084	26.1%	178692	73.9%
2005	61054	26.2%	172020	73.8%
2006	59739	25.5%	174152	74.5%
2007	63658	27.2%	170390	72.8%
2008	65070	27.8%	168590	72.2%
2009	61923	25.9%	176798	74.1%
2010	64248	24.5%	197845	75.5%
2011	58230	24.9%	175507	75.1%
2012	66010	27.7%	172398	72.3%
2013	62606	26.7%	171593	73.3%

Appendix 5/1

The results of the detailed PEF intermediate calculation for electricity

Table 38. Detailed intermediate non-renewable PEF values for Electricity, 1st case

<table>
<tr><td>Type of electricity generation</td><td>Hydro power</td><td>Wind power</td><td>Nuclear power</td><td>Conventional condensing power</td><td>CHP, industry</td><td>CHP, district heat, 1st case</td><td rowspan="2">∑, non-renewable PEF</td></tr>
<tr><td>Initial Data for PEF calculations</td><td colspan="3">Table 9, Table 10</td><td>Appendix 4/1</td><td>Appendix 4/2</td><td>Appendix 4/3</td></tr>
<tr><td>Initial data for energy type contribution</td><td colspan="7">Appendix 3</td></tr>
<tr><td>Multiplier / Year</td><td></td><td></td><td></td><td></td><td></td><td>1.14</td><td></td></tr>
<tr><td>2000</td><td rowspan="14">0.01</td><td rowspan="14">0.03</td><td rowspan="14">3.47</td><td>1.877</td><td>0.585</td><td>1.773</td><td>1.756</td></tr>
<tr><td>2001</td><td>1.614</td><td>0.614</td><td>1.784</td><td>1.776</td></tr>
<tr><td>2002</td><td>1.768</td><td>0.572</td><td>1.745</td><td>1.819</td></tr>
<tr><td>2003</td><td>1.884</td><td>0.560</td><td>1.737</td><td>1.874</td></tr>
<tr><td>2004</td><td>1.845</td><td>0.558</td><td>1.714</td><td>1.731</td></tr>
<tr><td>2005</td><td>1.457</td><td>0.570</td><td>1.695</td><td>1.746</td></tr>
<tr><td>2006</td><td>1.797</td><td>0.518</td><td>1.680</td><td>1.786</td></tr>
<tr><td>2007</td><td>1.721</td><td>0.515</td><td>1.657</td><td>1.722</td></tr>
<tr><td>2008</td><td>1.508</td><td>0.506</td><td>1.644</td><td>1.622</td></tr>
<tr><td>2009</td><td>1.887</td><td>0.536</td><td>1.631</td><td>1.820</td></tr>
<tr><td>2010</td><td>1.751</td><td>0.505</td><td>1.550</td><td>1.731</td></tr>
<tr><td>2011</td><td>1.469</td><td>0.496</td><td>1.504</td><td>1.705</td></tr>
<tr><td>2012</td><td>1.538</td><td>0.455</td><td>1.436</td><td>1.618</td></tr>
<tr><td>2013</td><td>1.798</td><td>0.391</td><td>1.467</td><td>1.745</td></tr>
</table>

Appendix 5/2
The results of the detailed PEF intermediate calculation for electricity

Table 39. Detailed intermediate non-renewable PEF values for Electricity, 2nd case

Type of electricity generation	Hydro power	Wind power	Nuclear power	Conventional condensing power	CHP, industry	CHP, district heat, 2nd case	∑, non-renewable PEF
Initial Data for PEF calculations	Table 9, Table 10			Appendix 4/1	Appendix 4/2	Appendix 4/3	
Initial data for energy type contribution	Appendix 3						
Multiplier / Year						0.89	
2000	0.01	0.03	3.47	1.877	0.585	1.384	1.679
2001				1.614	0.614	1.393	1.694
2002				1.768	0.572	1.363	1.735
2003				1.884	0.560	1.356	1.798
2004				1.845	0.558	1.338	1.656
2005				1.457	0.570	1.323	1.660
2006				1.797	0.518	1.311	1.713
2007				1.721	0.515	1.293	1.651
2008				1.508	0.506	1.283	1.548
2009				1.887	0.536	1.273	1.739
2010				1.751	0.505	1.210	1.653
2011				1.469	0.496	1.174	1.633
2012				1.538	0.455	1.121	1.551
2013				1.798	0.391	1.145	1.678

Appendix 5/3

The results of the detailed PEF intermediate calculation for electricity

Table 40. Detailed intermediate total PEF values for Electricity, 1st case

Type of electricity generation	Hydro power	Wind power	Nuclear power	Conventional condensing power	CHP, industry	CHP, district heat	∑, total PEF
Initial Data for PEF calculations	Table 9, Table 10			Appendix 4/1	Appendix 4/2	Appendix 4/3	
Initial data for energy type contribution	Appendix 3						
Multiplier / Year						1.14	
2000	1.01	1.03	3.5	2.584	2.786	2.594	2.573
2001				2.621	2.771	2.598	2.612
2002				2.589	2.792	2.611	2.664
2003				2.524	2.791	2.621	2.667
2004				2.558	2.797	2.609	2.570
2005				2.707	2.789	2.609	2.620
2006				2.555	2.802	2.650	2.651
2007				2.620	2.810	2.654	2.616
2008				2.678	2.809	2.626	2.546
2009				2.596	2.798	2.656	2.637
2010				2.619	2.813	2.660	2.633
2011				2.689	2.815	2.705	2.663
2012				2.688	2.838	2.775	2.566
2013				2.612	2.864	2.776	2.661

Appendix 5/4

The results of the detailed PEF intermediate calculation for electricity

Table 41. Detailed intermediate total PEF values for Electricity, 2nd case

Type of electricity generation	Hydro power	Wind power	Nuclear power	Conventional condensing power	CHP, industry	CHP, district heat	∑, total PEF
Initial Data for PEF calculations	Table 9, Table 10			Appendix 4/1	Appendix 4/2	Appendix 4/3	
Initial data for energy type contribution	Appendix 3						
Multiplier / Year						0.89	
2000	1.01	1.03	3.5	2.584	2.786	2.244	2.503
2001				2.621	2.771	2.248	2.538
2002				2.589	2.792	2.258	2.586
2003				2.524	2.791	2.266	2.596
2004				2.558	2.797	2.256	2.501
2005				2.707	2.789	2.256	2.538
2006				2.555	2.802	2.288	2.579
2007				2.620	2.810	2.292	2.546
2008				2.678	2.809	2.269	2.473
2009				2.596	2.798	2.293	2.554
2010				2.619	2.813	2.296	2.550
2011				2.689	2.815	2.331	2.581
2012				2.688	2.838	2.386	2.483
2013				2.612	2.864	2.387	2.580

Appendix 6/1

The results of the detailed PEF intermediate calculation for district heating

Table 42. Intermediate PEF values for detailed non-renewable DH PEF calculation according to the IINAS

Type of DH generation	CHP, district heating		Separate heat production	IINAS, non-renewable detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	0.445	0.689	0.985	0.592	0.770
2001	0.447	0.693	1.001	0.587	0.771
2002	0.438	0.679	0.944	0.570	0.748
2003	0.437	0.677	0.927	0.559	0.739
2004	0.431	0.669	0.949	0.566	0.742
2005	0.427	0.662	0.937	0.561	0.734
2006	0.425	0.659	0.898	0.546	0.720
2007	0.419	0.649	0.882	0.545	0.713
2008	0.415	0.643	0.854	0.537	0.702
2009	0.412	0.638	0.912	0.541	0.709
2010	0.392	0.608	0.907	0.518	0.681
2011	0.382	0.592	0.815	0.490	0.648
2012	0.366	0.568	0.876	0.507	0.653
2013	0.374	0.579	0.839	0.498	0.648

Appendix 6/2

The results of the detailed PEF intermediate calculation for district heating

Table 43. Intermediate PEF values for detailed non-renewable DH PEF calculation according to the EN15603:2008

Type of DH generation	CHP, district heating		Separate heat production	EN15603:2008, non-renewable detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	0.402	0.623	0.958	0.553	0.714
2001	0.403	0.624	0.977	0.548	0.714
2002	0.395	0.612	0.916	0.530	0.691
2003	0.392	0.608	0.909	0.521	0.683
2004	0.390	0.605	0.932	0.532	0.690
2005	0.387	0.600	0.918	0.526	0.683
2006	0.379	0.588	0.881	0.507	0.663
2007	0.375	0.581	0.867	0.509	0.659
2008	0.376	0.583	0.837	0.505	0.654
2009	0.370	0.574	0.891	0.505	0.656
2010	0.356	0.552	0.883	0.485	0.633
2011	0.343	0.531	0.788	0.454	0.595
2012	0.322	0.499	0.843	0.466	0.594
2013	0.327	0.507	0.799	0.453	0.585

Appendix 6/3

The results of the detailed PEF intermediate calculation for district heating

Table 44. Intermediate PEF values for detailed non-renewable DH PEF calculation according to the ISO/DIS 52000-1:2015 E

Type of DH generation	CHP, district heating		Separate heat production	ISO/DIS 52000-1:2015 E, non-renewable detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	0.336	0.520	0.815	0.466	0.601
2001	0.336	0.522	0.829	0.461	0.599
2002	0.331	0.513	0.785	0.449	0.584
2003	0.329	0.510	0.782	0.442	0.577
2004	0.328	0.508	0.798	0.450	0.584
2005	0.326	0.505	0.788	0.447	0.579
2006	0.320	0.495	0.762	0.432	0.563
2007	0.316	0.491	0.752	0.435	0.562
2008	0.318	0.493	0.730	0.433	0.559
2009	0.314	0.486	0.768	0.431	0.559
2010	0.304	0.471	0.762	0.416	0.543
2011	0.294	0.456	0.695	0.394	0.516
2012	0.279	0.433	0.733	0.405	0.516
2013	0.283	0.438	0.701	0.394	0.508

Appendix 6/4

The results of the detailed PEF intermediate calculation for district heating

Table 45. Intermediate PEF values for detailed non-renewable DH PEF calculation according to the Ecoheatcool

Type of DH generation	CHP, district heating		Separate heat production	Ecoheatcool, non-renewable detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	0.336	0.521	0.792	0.460	0.595
2001	0.338	0.523	0.807	0.456	0.595
2002	0.331	0.513	0.759	0.442	0.577
2003	0.329	0.510	0.752	0.434	0.570
2004	0.327	0.507	0.770	0.443	0.575
2005	0.324	0.503	0.759	0.438	0.570
2006	0.319	0.494	0.729	0.424	0.554
2007	0.315	0.488	0.718	0.425	0.551
2008	0.316	0.489	0.694	0.421	0.546
2009	0.311	0.482	0.738	0.422	0.548
2010	0.299	0.464	0.732	0.405	0.529
2011	0.289	0.448	0.657	0.381	0.500
2012	0.273	0.424	0.701	0.392	0.501
2013	0.278	0.430	0.667	0.382	0.494

Appendix 6/5

The results of the detailed PEF intermediate calculation for district heating

Table 46. Intermediate PEF values for total detailed DH PEF calculation according to the IINAS

Type of DH generation	CHP, district heating		Separate heat production	IINAS, total detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	1.186	1.289	1.369	1.236	1.311
2001	1.188	1.292	1.367	1.233	1.311
2002	1.186	1.289	1.368	1.234	1.309
2003	1.188	1.291	1.355	1.229	1.307
2004	1.184	1.285	1.356	1.229	1.303
2005	1.182	1.282	1.357	1.228	1.302
2006	1.188	1.292	1.353	1.230	1.307
2007	1.186	1.288	1.349	1.230	1.305
2008	1.180	1.279	1.350	1.227	1.299
2009	1.183	1.283	1.358	1.228	1.302
2010	1.175	1.271	1.361	1.221	1.293
2011	1.178	1.276	1.357	1.223	1.296
2012	1.182	1.283	1.368	1.234	1.306
2013	1.185	1.287	1.374	1.236	1.310

Appendix 6/6

The results of the detailed PEF intermediate calculation for district heating

Table 47. Intermediate PEF values for total detailed DH PEF calculation according to the EN15603:2008

Type of DH generation	CHP, district heating		Separate heat production	EN15603:2008, total detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	1.118	1.182	1.274	1.160	1.207
2001	1.118	1.183	1.278	1.158	1.207
2002	1.116	1.180	1.266	1.155	1.202
2003	1.116	1.179	1.263	1.152	1.200
2004	1.115	1.178	1.268	1.155	1.202
2005	1.114	1.177	1.265	1.154	1.200
2006	1.113	1.175	1.257	1.150	1.196
2007	1.112	1.173	1.254	1.151	1.195
2008	1.112	1.173	1.248	1.150	1.194
2009	1.111	1.171	1.260	1.149	1.194
2010	1.107	1.166	1.258	1.144	1.189
2011	1.105	1.162	1.239	1.138	1.181
2012	1.101	1.156	1.251	1.142	1.182
2013	1.102	1.158	1.243	1.139	1.180

Appendix 6/7

The results of the detailed PEF intermediate calculation for district heating

Table 48. Intermediate PEF values for total detailed DH PEF calculation according to the ISO/DIS 52000-1:2015 E

Type of DH generation	CHP, district heating		Separate heat production	ISO/DIS 52000-1:2015 E, total detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	1.051	1.080	1.130	1.073	1.093
2001	1.051	1.080	1.129	1.071	1.092
2002	1.052	1.080	1.134	1.073	1.094
2003	1.052	1.081	1.134	1.072	1.094
2004	1.052	1.081	1.132	1.073	1.094
2005	1.052	1.081	1.132	1.073	1.094
2006	1.053	1.082	1.135	1.074	1.096
2007	1.053	1.083	1.136	1.076	1.097
2008	1.053	1.082	1.138	1.077	1.098
2009	1.054	1.083	1.134	1.074	1.096
2010	1.055	1.085	1.136	1.075	1.097
2011	1.056	1.086	1.143	1.078	1.101
2012	1.057	1.088	1.139	1.080	1.102
2013	1.056	1.087	1.142	1.079	1.102

Appendix 6/8
The results of the detailed PEF intermediate calculation for district heating

Table 49. Intermediate PEF values for total detailed DH PEF calculation according to the SAP 2012

Type of DH generation	CHP, district heating		Separate heat production	SAP 2012, total detailed PEF for district heating	
	1st case	2nd case		1st case	2nd case
Initial Data for PEF calculations	Appendix 4/3		Appendix 4/4		
Initial data for energy type contribution	Appendix 4/5				
Multiplier / Year	0.4	0.62			
2000	1.066	1.102	1.180	1.097	1.123
2001	1.065	1.101	1.176	1.093	1.120
2002	1.066	1.102	1.182	1.096	1.123
2003	1.065	1.101	1.181	1.094	1.121
2004	1.068	1.105	1.182	1.097	1.125
2005	1.069	1.106	1.183	1.098	1.126
2006	1.066	1.102	1.186	1.096	1.123
2007	1.067	1.104	1.191	1.101	1.127
2008	1.070	1.108	1.199	1.106	1.133
2009	1.068	1.106	1.190	1.100	1.128
2010	1.072	1.112	1.190	1.101	1.131
2011	1.071	1.111	1.196	1.102	1.132
2012	1.070	1.109	1.193	1.104	1.132
2013	1.070	1.108	1.196	1.104	1.132