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A comparative study about the Calculation of Primary energy factor (PEF) values of electricity generation for the policymaking in the Energy sector

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ABSTRACT

The stability between the limited available energy resources and their consumption is an important concern of the modern world. The study deals with the development of the methods for measuring the energy performance of different renewable and non-renewable resources used for electricity generation with the help of an energy performance indicator called the Primary Energy Factor (PEF). This study takes account of all energy stages from the resources extraction to its transportation, conversion, combustion and then finally to utilization. The study conducted a comparative approach to calculate the PEF values of electricity generated in South Korea from the period of 1980 to 2017. Four different methodologies namely Eurostat methodology, Life cycle methodology, Modified Eurostat methodology, and upper-end methodology have been used. A set of Programs has been written in MATLAB to calculate the

i. PEF values of electricity generated.
ii. Impact of different renewable and non-renewable energy sources on PEF values.
iii. Future trend of PEF values of electricity in South Korea.

At the national and local level, this study will help the government and other law-making institutions to make policies regarding annual purchase consumptions of energies by different industrial, residential, public and transportation sectors and at the Global level, the implementation of this study will be the catastrophe of maintaining the stability between the available energy resources, and consumptions. This, in turn, will lead to the suitable living conditions for future generations

Keywords: Primary energy factor (PEF); Energy Analysis of South Korea; Electricity analysis.

1. Introduction

The World population is about 7.5 billion and it will increase to around 13 billion in 2100. [1,2]. The earth resources are continuously decreasing and there is no visible way to sustain the earth's resources. The planet earth has already lost its stability in different shapes and spheres and it’s not possible to reset it

[3]. The humanity should maintain the stability between natural resources and its utilization to provide a stable living condition for future generations [4]. It is very important to keep track of all the energy resources that have been used and make their uses as economical as possible.

South Korea is the 8th largest consumer of energy in the world and relies on the import of energy resources to fulfill its energy demand due to the lack of domestic energy resources. According to BP Statistical Review of World Energy 2018, the consumption of petroleum products in 1990 was 1 million barrels per day, the trend of using the petroleum products has been continuously increasing in South Korea and it reaches to 2.7 million barrels per day and oil demand rose to 0.3 million barrels per day in 2017.

About 44 % of energy consumption in South Korea depends on the petroleum and other liquid, 29% on coal energy and 11% on nuclear energy in 2017. South Korea has to import about 98% of fossil fuel energy consumption. In 2017, it imported about 3 billion barrels/day of crude oil that made south Korea the 5th biggest importer of crude. South Korea import most of the oil supply from the middle east. About 29% of crude oil comes from Saudia Arabia, 15% from Kuwait and 12% from Iran and Saudia Arabia [5-6]

The resources of natural gas in South Korea is almost negligible. It is even less than 1 %. There are not any international gas pipelines connected to the south Korea so the only source of importing gas is through tankers of Liquified natural gas. Still, South Korea is the 3rd largest consumption of natural gas in the world.

The Korea Gas Corporation (KOGAS) is the largest company or organization in South Korea that imports the largest share of gas. The other local companies are allowed to import LNG only according to the terms and conditions of KOGAS [7].

According to US energy information administration, natural gas consumption was recorded in the year 2000 as 600 billion cubic feet. In 2005, it increases to 1200 billion cubic feet. The highest consumption was recorded in 2016, i.e. 1800 billion cubic feet and in 2017, it decrease to1400 cubic feet. The 17% share of all the natural gas consumption was used by the industrial sector, 30% was used by the residential consumers and only 3% was used by the transportation sector

2. Literature Review

South Korea heavily depends on fossil fuels and nuclear sources for the generation of electricity. About 2/3 of electricity generation of South Korea depends on fossil fuels and 1/3 depend on Nuclear resources. The Government made the initiative to increase its dependence on renewable energy sources which are more environmentally friendly.

According to Korea energy economics 2017, South Korea has generated about 550,441 GWh of electricity in 2017. The electricity generation in 2012 was about 5% lower than in the last decade. In 2016, 40% of entire electricity was generated from coal, 30% was from nuclear, 22% was from natural gas and 4% was from renewable sources. The industrial sector consumed about 54% of generated electricity, the commercial sector consumed about 26% and the transportation sector consumed about 13% of generated electricity [8].
Since South Korea relies on the import of energy sources to fulfill its energy demand, it is very important to track the energy been generated and transmitted.

This study focused on the development of the primary energy factor for heat and electricity in South Korea. The PEF consider the energy consumption for the conveyance and transmission of the carriers of energy, furthermore, it also considers the productivity of conversion or conversions from Primary Energy (PE) to Final Energy (FE). The vitality execution of a building depends on the features of the buildings as well as on the features of energy supply [9].

The performance of any building regarding energy efficiency is the net of all the delivered energies to meet its energy requirements. [EN/TR 15615 (CEN 2008)]. The assessment of the energy performance of buildings has a twofold reason.

- The energy requirement of new and old buildings.
- The PEF value of the buildings.

For both at national and regional level building sectors, the concept of PEF is very important regarding the energy policy of the buildings. They can coordinate the decision among various carriers of energy used to meet the building vitality needs, in light of the fact that the building vitality execution appraisal results depend specifically on their values. The PEF can also direct to the reduction of CO_2 emission, increase the efficiency of energy at the user's end.

There are two kinds of energy.
Primary energy
Secondary energy

Both energies have different dimensions and represent a different form of energy. They are also known as source energy [10,11]. The energy performance of two buildings cannot be compared together if they represent the different genres of energy. For the Primary energy of electricity estimation, the energy losses in the generation, transportation, and distribution of electricity also taken into consideration unlike in the secondary form of energy [12]. It takes more than 1 unit of energy resources like fossil fuels, petroleum, and natural gas to generate 1 unit of electricity [13]. Likewise, the energy resources like renewables, biomass, waste, and others should be taken into account while calculating the Primary energy. All the secondary sources of energy should include evaluating primary energy consumption [14]. Primary energy evaluation also predicts with greater accuracy about the carbon emission factor which is highly important for environmental sustainability.

Overgaard [15] argue that primary and secondary energy should be kept separated. It will help to present a clear picture of energy consumption. The PEF considers the energy consumption for the conveyance and transmission of the carriers of energy, furthermore, it also considers the productivity of conversion or conversions from Primary Energy (PE) to Final Energy (FE). [16,17]. Marcogaz [18] suggested that if the PEF is calculated using all the renewable energy sources, it will be called the Total primary energy factor. Pout [19] suggested the inclusion of both renewable and nonrenewable energy sources for the calculation of primary energy factor. Many studies suggesting the system boundaries before evaluating primary energy consumption. The system boundaries must include energy and no energy inputs

Dijk [20] and CEN [21] calculate the primary energy factor by taking account of the energy extraction from resources, conversion, transmission and usage. Molenbroek [22] suggested to include all the energy losses while calculating the primary energy factor.

3. Methods and Materials

3.1. Indicators of Primary energy factor

3.1.1. Significance of Primary energy factor

According to EN/TR 15615 (CEN 2008), the energy that has not been exposed to any change or change process is known as Primary energy. For instance the petroleum products. The final energy comes from primary energy after being transformation and passing through the multiple processes.

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The reason of calculating PEF is to weigh the carriers of energy with respect to the source of energies. It is basically the numerical coefficients, defined as

PEF = Unit of energy transmitted / n units of PE consumed to deliver it.

The PEF consider the energy consumption for the conveyance and transmission of the carriers of energy, furthermore it also considers the productivity of conversion or conversions from PE to FE. The vitality execution of a building depends on the features of the buildings as well as on the features of the energy supply.

The performance of any building regarding energy efficiency is the net of all the delivered energies to meet its energy requirements. [EN/TR 15615 (CEN 2008)]. The assessment of the energy performance of buildings has a twofold reason.

i. The energy requirement of new and old buildings.
ii. The PEF value of the buildings.

For both at national and regional level building sectors, the concept of PEF is very important regarding the energy policy of the buildings. They can coordinate the decision among various carriers of energy used to meet the building vitality needs, in light of the fact that the building vitality execution appraisal results depend specifically on their values. The PEF can also direct to the reduction of CO_2 emission, increase the efficiency of energy at the user's end. There are three kinds of Primary energy factors. The fig. 1 below shows how the different PEF connected to each other.

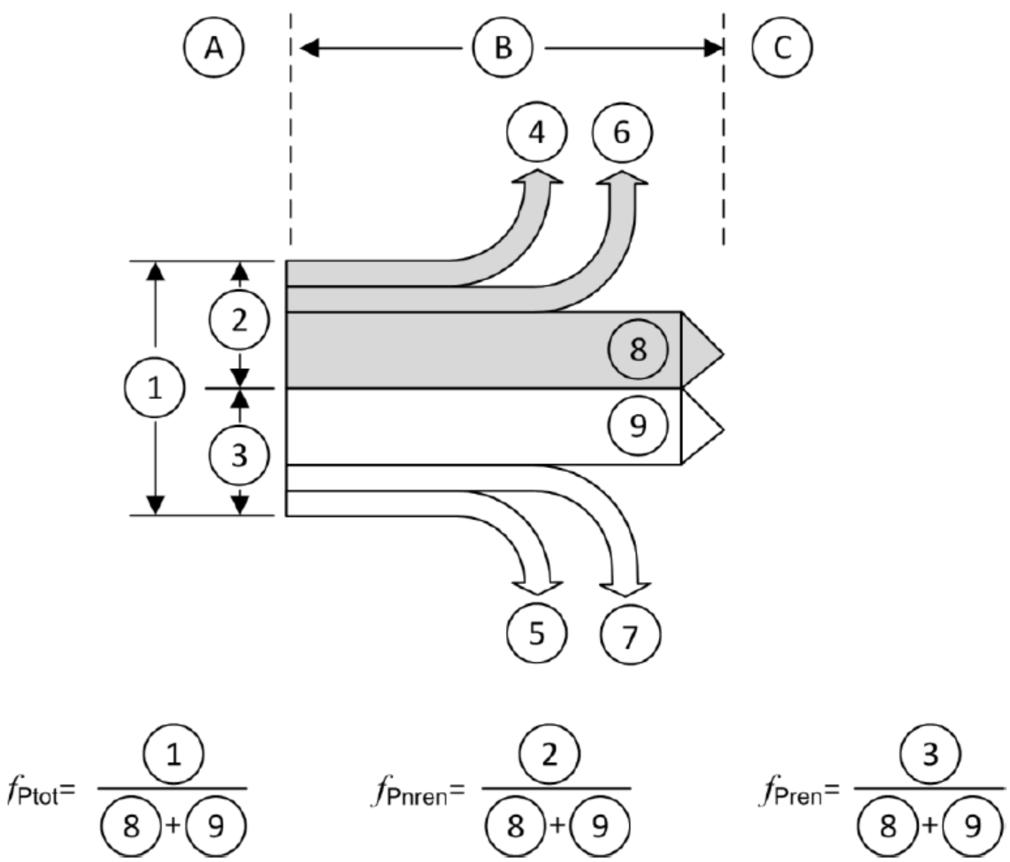

Figure 1. Primary energy factor and Primary energy flows

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1= Total primary energy. Sum of both non-renewable and renewable primary energy.

2 = Portion of Non-Renewable Primary energy

3 = Portion of Renewable Primary energy

4= Energy related to infrastructure (Non-Renewable energy)

5= Energy related to infrastructure (Renewable energy)

6= Energy loss during conversion and transformation (Non-Renewable energy)

7= Energy loss during conversion and transformation (Renewable energy)

8= Final Non-renewable energy consumption

9= Final Renewable energy Consumption.

f_p= Total Primary energy factor

f_{nrew} = Non-Renewable primary energy factor

f_{ren} = Renewable Primary energy factor

3.1.1.1.Total Primary energy factor

The total energy factor is the ratio of the sum of both renewable and non-renewable primary energy sources to the final energy delivered.

3.1.1.2.Renewable Primary energy factor

The renewable primary energy factor is the ratio of renewable primary energy sources to the final energy delivered.

3.1.1.3.Non-renewable primary energy factor.

The total energy factor is the ratio of the sum of both renewable and non-renewable primary energy to the final energy delivered.

3.1.2. Establishing the boundaries of the system

One of the most important stages is to define the boundary of the system. The Boundary of the system can be defined in ways.

3.1.2.1.Entire Supply chain

The entire supply chain method follows the Life cycle assessment (LCA) method and includes the expenditure of energy from the source extraction to the transportation, conversion into the useful energy, combustion, transportation and the final generation of electricity as shown in the figure below.

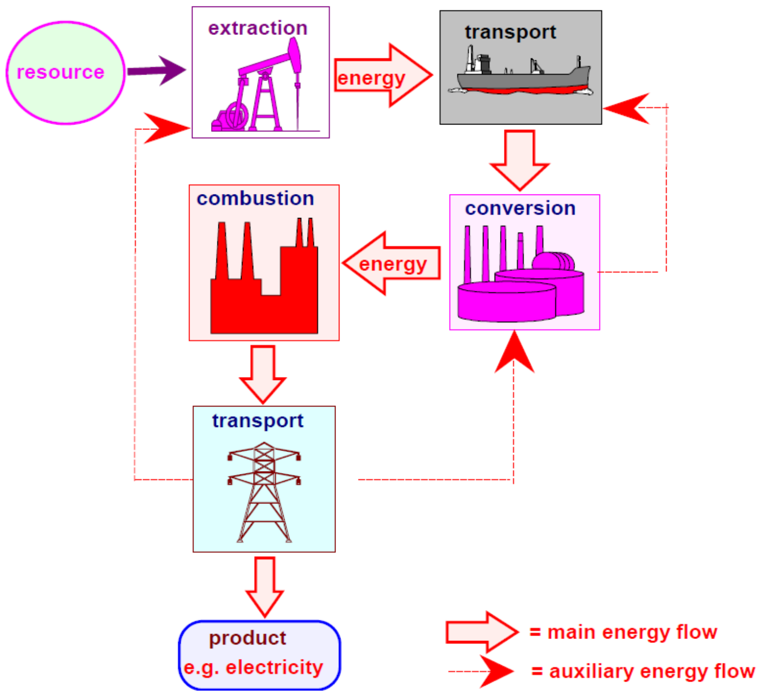

Figure 2. Schematic of entire supply chain energy flow

3.1.2.2.Energy Conversion and transmission only

The other method of defining the system boundary is to take the energy expenditure on the conversion and transmission only.

3.1.3. Evaluation method for the Primary energy

There are many methods for the evaluation of Primary energy according to the sources. The following study divided the evaluation of primary energy methods according to Non-Combustible non-renewable energy sources (Nuclear energy), Non-Combustible renewable energy sources (hydro, wind, steam, Solar, etc.) and fossil fuels.

The downstream Primary energy will also be taken into consideration apart from the primary energy of fuel if the entire supply chain has been defined as the boundary of the system.

3.1.4. The accounting method for the nuclear electricity Generation

3.1.4.1.Direct equivalent method

This energy evaluation method is particularly assigned for the Non- Combustible fuels by the UN. For the non-combustible fuels, the energy contents are hard to determine, the percentage of transformation efficiency of fuel into electricity in this method is 100%.

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3.1.4.2.Physical energy content method and Technical conversion efficiency method

The technical conversion efficiency and physical energy content method have been extensively used by the International Energy Agency (IEA). These methods established the transformation efficiency of fuel into electricity only 33% and PEF value 1.00.

3.1.5. Accounting Method for the non-combustible Renewable energy sources.

3.1.5.1. Zero equivalent method (For Non-combustible fuels)

This method does not take the primary energy into consideration for the transformation of fuels into electricity.

3.1.5.2. Substitution method

This method considers the potential energy of the source as the primary energy before any transformation occurs. For example, to use the substitution method the velocity and the mass of the air would be needed first to calculate the kinetic energy of the air if the energy source is a wind turbine. This method is extensively used by the Energy Information Administration US.

3.1.5.3. Direct equivalent method

The method assigned the PEF value of 1.00 to all the non-combustible renewable energy sources and not valid for combustible renewable energy sources like biomass. This method depicts the positive effects of non-combustible renewable energy sources on climate change.

3.1.5.4. Physical energy content method

The method considers the primary energy as initial or original energy before it has been used for different purposes. It assigned the primary energy factor value of unity for the transformation of non-combustible renewable energy sources into electricity. This method has been extensively used by IEA.

3.1.5.5. Technical Conversion efficiencies

In this method, the real data has been used to determine the conversion or transformation efficiency. It assigned the PEF value of unity for the transformation of all the non-combustible renewable energy sources into electricity.

3.1.6. The accounting method for the combustible renewable energy sources

The only 2 methods available to evaluate the Primary energy contents of Combustible renewable energy sources

- Zero equivalent method
- Technical Conversion efficiency method

The zero equivalent method is used if the purpose is to the evaluation of only non-renewable part of energy while the technical conversion efficiency method is used if the renewable part of the energy is taken into consideration.

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3.1.7. The accounting method for the Combine heat and power (CHP)

3.1.7.1.International Energy Agency (IEA method)

The method is largely used the Eurostat. The simplified version of this method is shown in the figure below

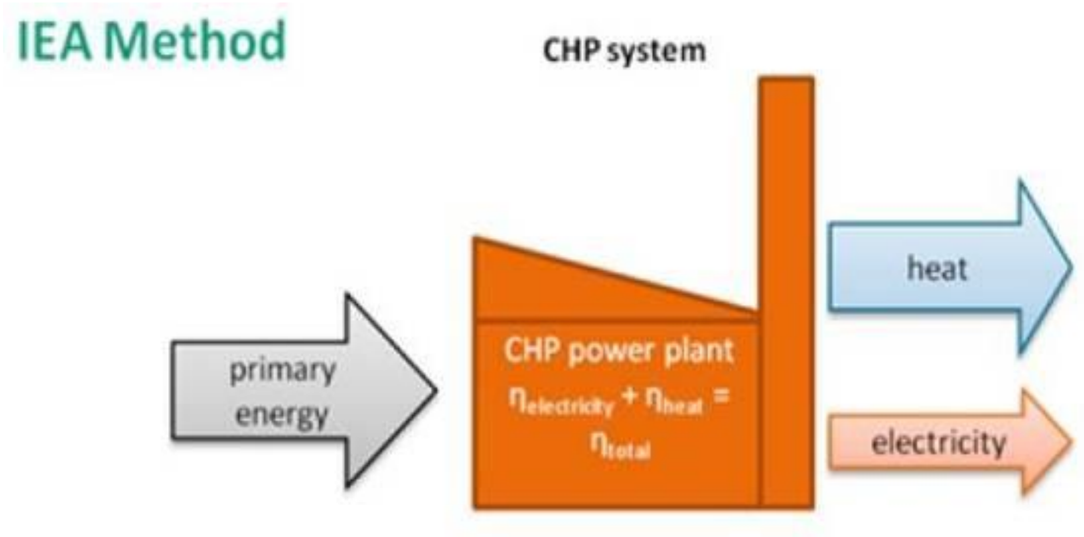

Figure 3. IEA method of evaluating CHP

$$PE\ Share\ of\ electricity = \frac{\eta electricity}{\eta electricity + \eta heat} \qquad (1)$$

$$\eta electricity = \text{Conversion efficiency of electricity}$$

$$\eta heat = \text{Conversion efficiency of heat}$$

In this method, the amount of primary energy attributed to both heat and electricity according to their output share. The conversion efficiency of electricity is divided to the conversion efficiency of both heat and electricity. In CHP process, the conversion efficiency of heat is always higher than electricity so the greater share of Primary energy allocated to the heat.

3.1.7.2.Finnish Method

The Finnish way of accounting CHP is shown in the figure below.

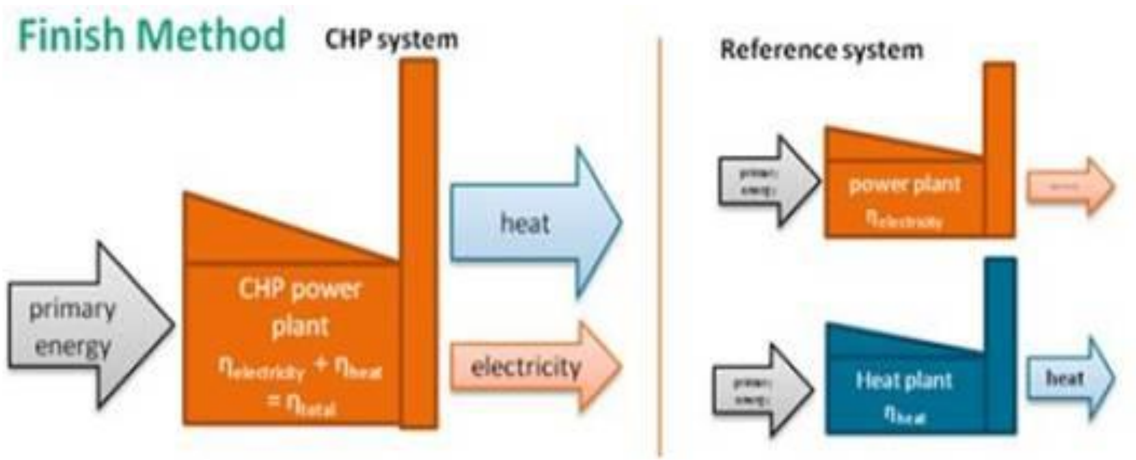

Figure 4. Finnish Method of evaluating CHP

$$PE\ share\ of\ electricity = (1 - PEE) * \frac{\eta\text{CHP,el}}{\eta\text{REF,el}} \quad (2)$$

$$PEE = \frac{\text{PE Ref– PECHP}}{\text{PERef}} = 1 - \frac{1}{\frac{\eta\text{CHP, heat}}{\eta\text{REF, heat}} + \frac{\eta\text{CHP, el}}{\eta\text{REF, el}}} \quad (3)$$

$$PEE = Primary\ energy\ savings\ compared\ to\ reference\ system$$

$$\eta\text{REF, el} = \text{Conversion efficiency of the reference electricity system}$$

$$\eta\text{REF, heat} = \text{Conversion efficiency of reference heat system}$$

In the first step, the Primary energy saving of CHP calculated with reference to the separate system. The electrical and thermal efficiencies of the CHP process calculated with reference to the electrical and thermal efficiencies of the independent system

In the 2nd step, the primary energy assigned to both the electricity and heat can be calculated.

3.1.8. List of equations used

The equation used in this method are as follows

3.1.8.1.Net electricity demand

Gross electricity generated (1- Grid losses – Self Consumption) (4)

3.1.8.2.Primary energy demand

Primary energy (PE) demand = $\frac{Gross\ electricity\ Generation\ x\ PEF\ fuel}{efficiency}$ (5)

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3.1.8.3. Raw Primary energy demand

Raw primary energy demand = $\sum fuel \frac{\textbf{Gross electricity generation x PEF fuel}}{\textbf{efficiency}}$ (6)

3.1.8.4. Heat calculation from the combined heat and power Plant

CHP Heat Generation= $\frac{\textbf{CHP electricity generation x (1−self consumption)}}{\textbf{electricity to heat ratio}}$ (7)

3.1.8.5. Calculation of fuel Consumption by CHP

Fuel Consumption= $\frac{CHP\ electricity\ generation + CHP\ heat\ generation}{CHP\ efficieny}$ (8)

3.1.8.6. Calculation of process efficiencies

CHP efficiency of heat generation = $\frac{CHP\ electricity\ generation}{CHP\ fuel\ consumption}$ (9a)

CHP efficiency of electricity generation = $\frac{CHP\ heat\ generation}{CHP\ fuel\ consumption}$ (9b)

3.1.8.7. Calculation of ratio efficiencies compared to alternative system efficiencies

Ratio efficiency of electricity = $\frac{CHP\ efficiency\ of\ electricty\ generated}{40\%}$ (10a)

Ratio efficiency Heat = $\frac{CHP\ efficiency\ of\ heat\ generated}{90\%}$ (10b)

3.1.8.8. Calculations of the efficiency factor

$$\text{Sum of Ratios efficiency} = \text{Ratio efficiency electricity} + \text{Ratio efficiency Heat} \quad (11a)$$

$$\text{Efficiency Factor } (1 - \text{PEE}) = \text{Sum of Ratios efficiency} - 100\% \quad (11b)$$

3.1.8.9. Calculation of heat Bonus

Heat Bonus = Fuel Consumption * Ratio efficiency heat*(1- PEE)* PEF $_{fuel}$ (12)

3.1.8.10. Calculation of Primary energy factor

$$\text{Final PEF electricity} = \frac{Raw\ Primary\ energy\ demand - Heat\ bonus\ CHP}{Net\ electricity\ demand} \quad (13)$$

3.2. Development of Primary energy factor of electricity

3.2.1. Calculation Method 1 – Eurostat Methodology

Method 1 is based on the Eurostat approach for the development of Primary energy factor. All the fuels consider for the development of the Primary energy factor of electricity has been given the value 1 and only the conversion and Transmission part of the energy has been considered. The figure below shows the road map for the development of the Primary energy factor. The efficiencies and PEF of different fuels calculated by Anke [23] have been used in this study.

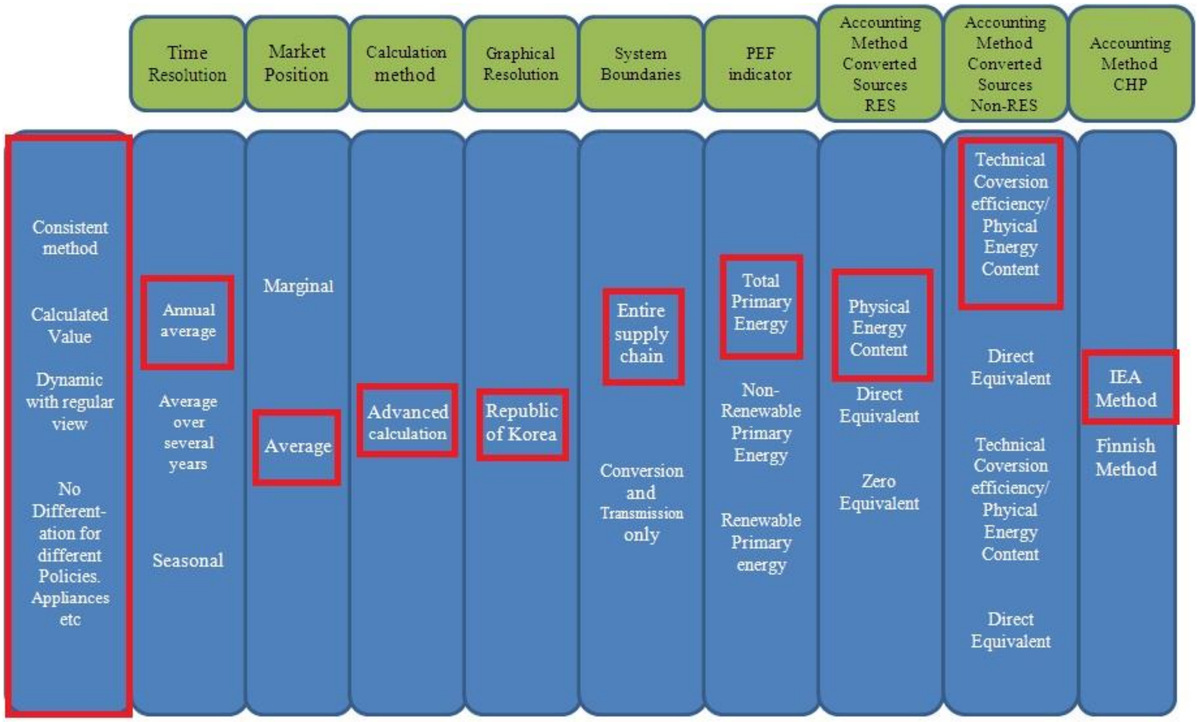


Figure 5. Decision path for the Eurostat Methodology

Table 1 shows the categories and indicators of the Eurostat Methodology.

Table 1. Categories and indicator for the Eurostat methodology

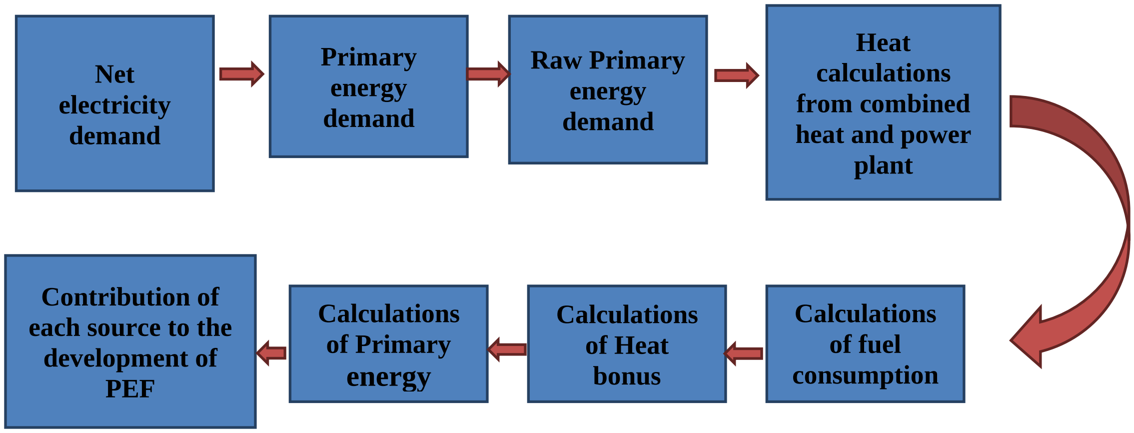
Categories	Indicator
Time Resolution	Annual Average
Market Position	Average
Method of calculation	Advanced
Geographical region	Republic of Korea
The boundary of the system	Only Transmission and Conversion Portion
Indicator of PEF	Total PEF
The accounting method for renewable energy sources	Physical energy content method
The accounting method for non-renewable energy sources	Technical Conversion efficiency method

The accounting method for the Combined heat and power plant	International Energy agency method

Table 2. Assumed PEF values and efficiencies for Eurostat methodology

Source		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Hydro	Efficiency	45%							
	PEF	1							
Nuclear	Efficiency	33%							
	PEF	1							
Coal	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF	1							
Petroleum	Efficiency	31%	35%	38%	40%	41%	43%	45%	47%
	PEF	1							
LNG	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF	1							
Steam	Efficiency	45%							
	PEF	1							
Renewable	Efficiency	45%							
	PEF	1							

The fig. 6 shows the roadmap to the calculation of the PEF of electricity according to Eurostat Methodology



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3.2.2.

3.1.2 **Figure 6. Roadmap to the calculation of primary energy factor (Eurostat Methodology)**

This method follows the Life Cycle Analysis (LCA) approach and only the non-renewable portion of the Primary energy factor has been considered. The entire supply chain has been taking into account for this method and the Finnish method has been used for accounting the CHP. For Fossil Fuel, the Primary energy factor for the coal, Petroleum, and LNG has been considered as 1.07, 1.11 and 1.13 for LCA Non-renewable PEF. The Fig. 7 shows the road map for the calculation method 2.

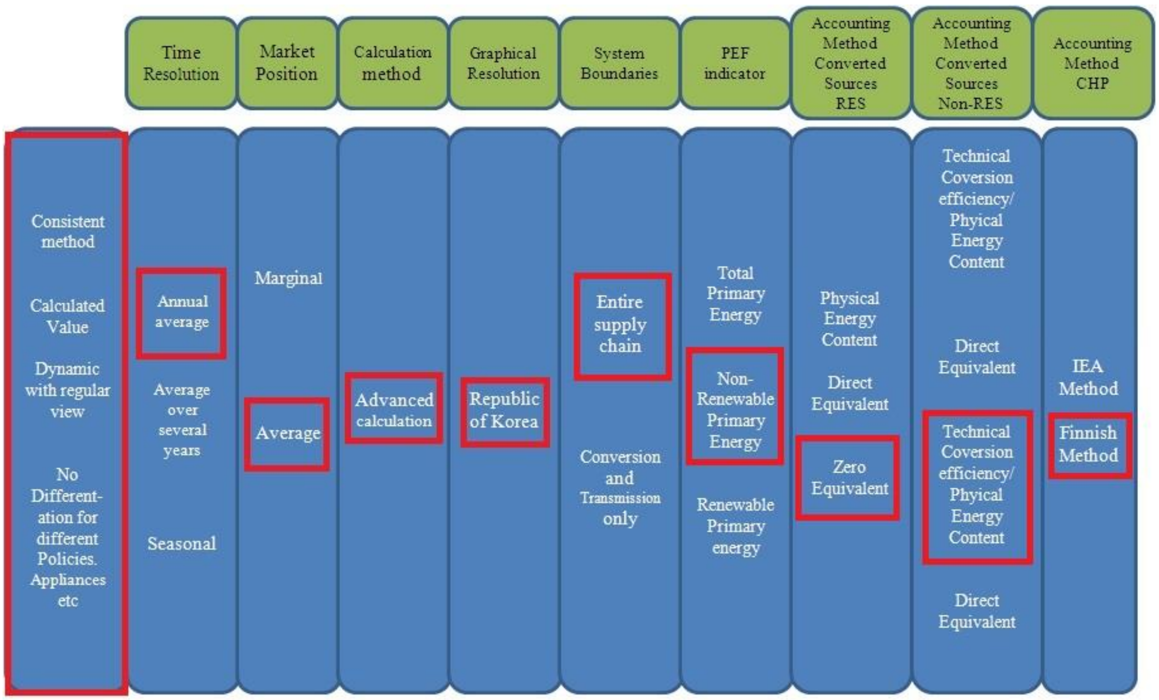

Figure 7. Decision path for the Life Cycle Approach

The table below shows the categories and indicator for the Life Cycle Approach

Table 3. Categories and indicator for the Life Cycle Approach

Categories	**Indicator**
Time Resolution	Annual Average
Market Position	Average
Method of calculation	Advanced

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Geographical region	Republic of Korea
The boundary of the system	Entire supply chain
Indicator of PEF	Non-Renewable Primary energy
The accounting method for renewable energy sources	Zero equivalent
The accounting method for non-renewable energy sources	Technical Conversion efficiency/ Physical energy content method
The accounting method for the Combined heat and power plant	Finnish Method

The table below shows the efficiency and PEF $_{fuel}$ for the Life Cycle Approach.

Table 4. Assumed PEF values and efficiencies for the Life Cycle Approach

Source		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Hydro	Efficiency	45%							
	PEF	0.06							
Nuclear	Efficiency	33%							
	PEF	1							
Coal	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF	1.07							
Petroleum	Efficiency	31%	35%	38%	40%	41%	43%	45%	47%
	PEF	1.11							
LNG	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF	1.13							
Steam	Efficiency	45%							
	PEF	0.07							
Renewable	Efficiency	45%							
	PEF	0.08							

Fig 8 shows the roadmap to the development of PEF of electricity according to Life Cycle methodology.

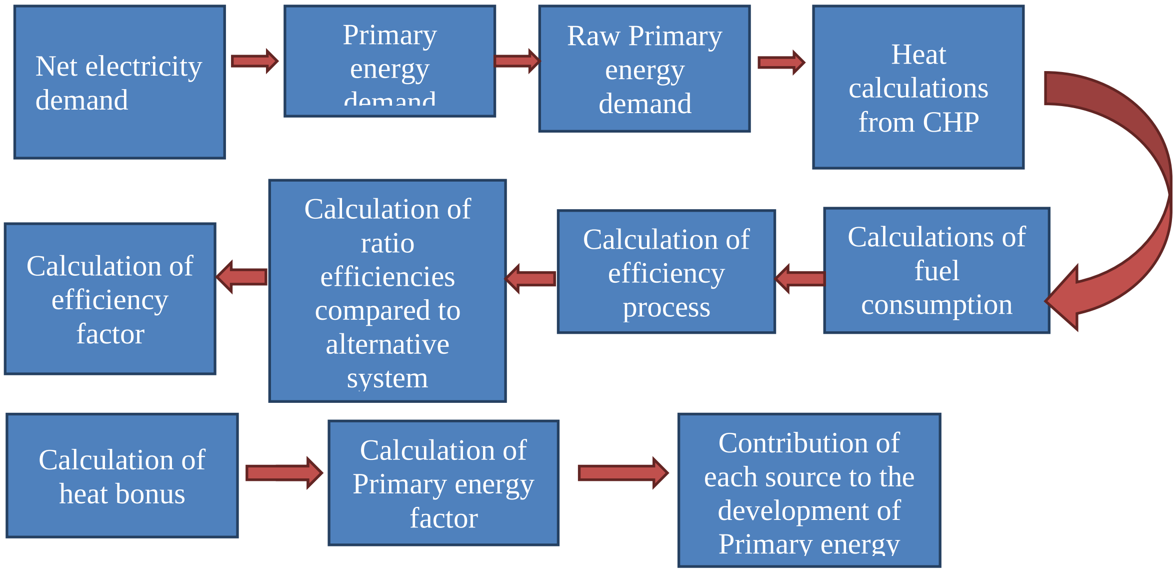

Figure 8. Roadmap to the development of primary energy factor (Life Cycle Methodology)

3.1.3. Calculation Method 3 – Modified Eurostat Methodology

The calculation method 3 is the modification of calculation method 1 and follows the same Eurostat methodology of accounting energy. The basic difference between them is the accounting method for the Combined Heat and Power Plant. For Method 1, the IEA method has been used and for Method 3, the finish method has been used to account for the CHP.

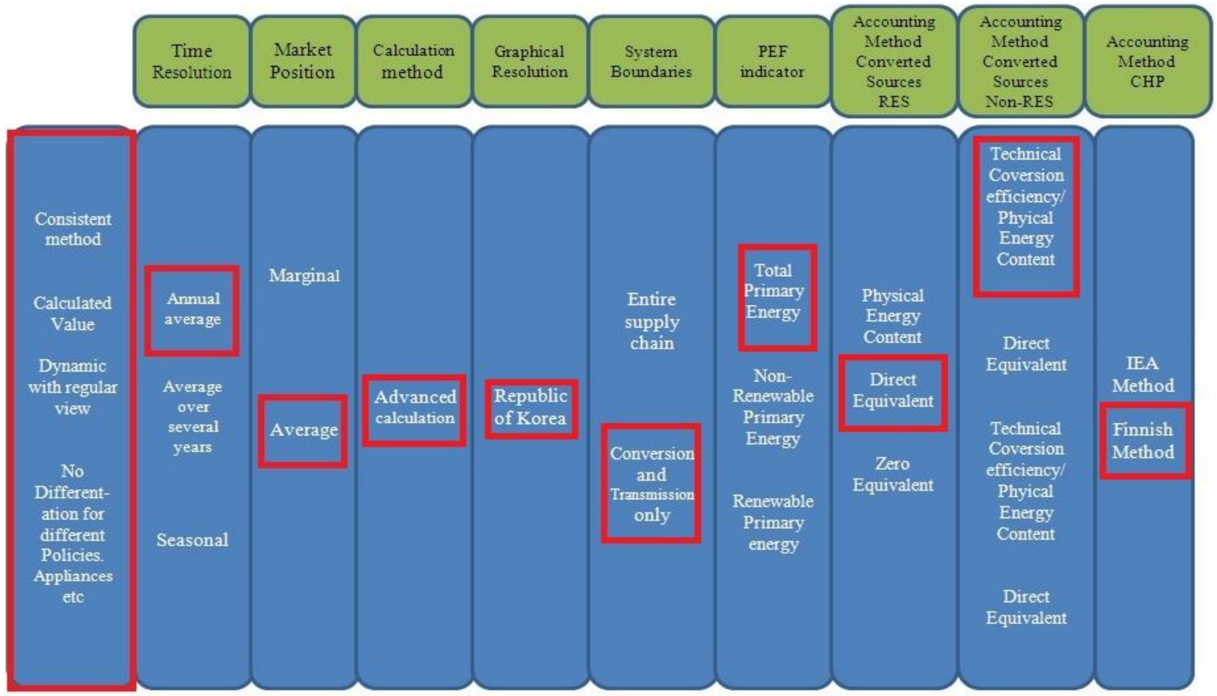

Figure 9. Decision path for the Modified Eurostat Methodology

The table below shows the categories and indicator for the Modified Eurostat Methodology

Table 5. Categories and indicator for the Modified Eurostat methodology

Categories	**Indicator**
Time Resolution	Annual Average
Market Position	Average
Method of calculation	Advanced
Geographical region	Republic of Korea
The boundary of the system	Only Conversion and transmission Portion
Indicator of PEF	Total Primary energy
The accounting method for renewable energy sources	Direct equivalent
The accounting method for non-renewable energy sources	Technical Conversion efficiency/ Physical energy content method
The accounting method for the Combined heat and power plant	Finnish Method

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The table 6 below shows the efficiency and PEF $_{fuel}$ for the calculation method

Table 6. Assumed PEF values and efficiencies for the Modified Eurostat methodology

Source		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Hydro	Efficiency	45%							
	PEF	1							
Nuclear	Efficiency	33%							
	PEF	1							
Coal	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF	1							
Petroleum	Efficiency	31%	35%	38%	40%	41%	43%	45%	47%
	PEF	1							
LNG	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF	1							
Steam	Efficiency	45%							
	PEF	1							
Renewable	Efficiency	45%							
	PEF	1							

The main difference between the modified and Eurostat modified methodology is the evaluation of electricity generation from CHP. The modified Eurostat methodology uses the Finnish method for the analysis of electricity generated from CHP unlike Eurostat methodology which uses the IEA method.

3.1.4. Calculation Method 4 – Upper-end Method

This method has been developed to explain the upper end of the Primary energy factor development option. This method taking into account the entire supply chain and follows the LCA approach for non-renewable fuels. The Primary energy factor of 1.11 has been chosen as an approximation of LCA total primary energy. The figure below shows the roadmap for the development of the Primary energy factor of electricity.

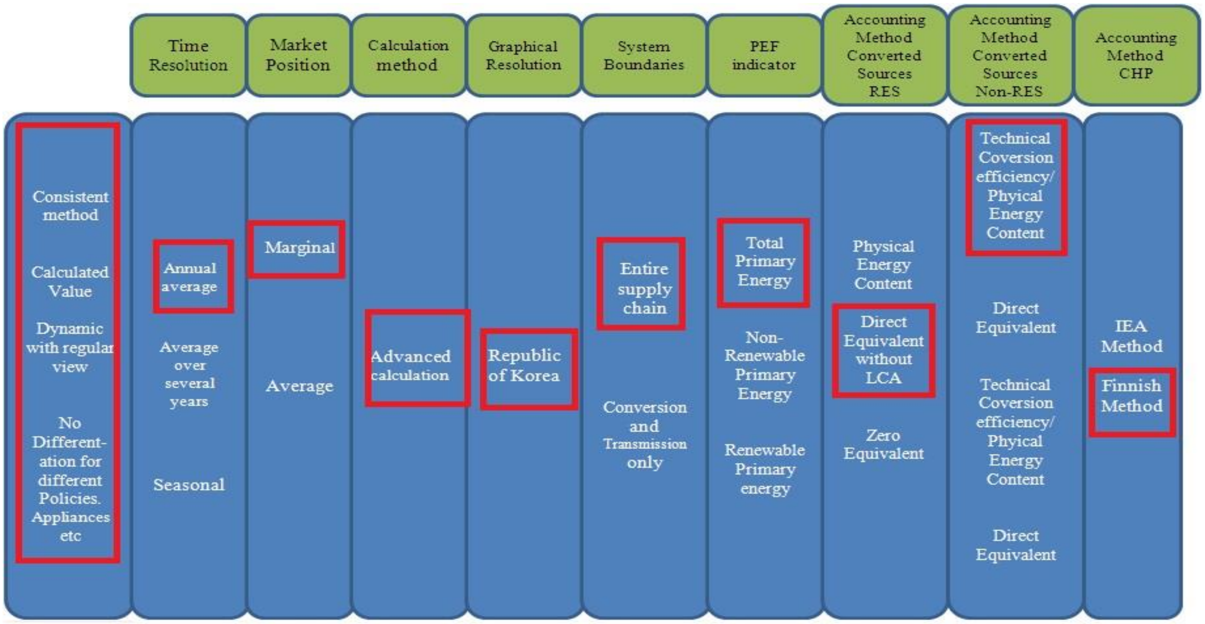

Figure 10. Decision path for the Upper-end Methodology

The table below shows the categories and indicator for the calculation method 4

Table 7. Categories and indicator for the Upper-end methodology

Categories	**Indicator**
Time Resolution	Annual Average
Market Position	Average
Method of calculation	Advanced
Geographical region	Republic of Korea
The boundary of the system	Entire Supply chain
Indicator of PEF	Total Primary energy
The accounting method for renewable energy sources	Direct equivalent with LCA
The accounting method for non-renewable energy sources	Technical Conversion efficiency/ Physical energy content method
The accounting method for the Combined heat and power plant	Finnish Method

The table below shows the efficiency and PEF_{fuel} for the Upper-end Methodology.

Table 8. Assumed PEF values and efficiencies for the Modified Eurostat methodology

Source		1980	1985	1990	1995	2000	2005	2010	2015
Hydro	Efficiency	45%							
	PEF	1							
Nuclear	Efficiency	33%							
	PEF	1							
Coal	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF	1.11							
Petroleum	Efficiency	31%	35%	38%	40%	41%	43%	45%	47%
	PEF	1.11							
LNG	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF	1.11							
Steam	Efficiency	45%							
	PEF	1							
Renewable	Efficiency	45%							
	PEF	1							

4. Results and Discussions

4.1. Development of Primary energy factor of electricity

4.1.2. Calculation Method 1- Eurostat Methodology

4.1.2.1.Calculations of net electricity demand

The Net electricity demand in South Korea has been shown in table 13 by considering the electricity generation from different sources. All values are in GWh

Table 9. Gross electricity generation in South Korea (GWh)

All values are in GWh								
Source	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Hydro	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
Nuclear	2,897	16,745	52,887	67,029	108,964	146,779	148,956	164,762

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Coal	2,530	17,639	19,961	48,813	97,538	133,658	197,916	204,230
Petroleum	32,071	19,964	18,856	42,045	26,142	17,733	12,878	31,616
LNG	-	250	9,604	21,296	28,156	58,118	96,734	100,783
Steam	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
Renewable	29	23.61	9.26	12.22	24.76	46.04	70.5	149
Combined cycle	258	58	619	20,521	26,863	57,457	94,012	100,598
others	-	-	-	-	3903	3163	12064	20904
Gross electricity generation	77.262	97,757	156,183	295,485	419,253	577,265	786,545	857,908
Self Consumption	5.1%	5.1%	5.0%	4.9%	4.8%	4.7%	4.6%	4.5%
Grid losses	7.2%	7.2%	7.0%	6.9%	6.8%	6.7%	5.9%	5.9%
Net electricity demand	65,075	85,048	137,441	260,026	373,135	513,765	707,890	772,117

4.1.2.2. Calculations of Raw Primary energy demand (RPED)

The RPED of the electricity generation for the Eurostat methodology has been shown in table 14.

Table 10. Raw Primary energy demand for electricity generation in South Korea

All values are in GWh									
Source	**Factors**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Hydro	Total electricity generation	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
	PE demand	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
	Efficiency	45%							
	PEF $_{fuel}$	1							

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Nuclear	Total electricity generation	2,897	16,745	52,887	67,029	108,964	146,779	148,596	164,762
	PE demand	8,778	50,742	160,263	203,118	330,193	444,784	450,290	499,278
	Efficiency	33%							
	PEF_{fuel}	1							
Coal	Total electricity generation	2,530	17,639	19,961	48,813	97,538	133,658	197,916	213,803
	PE demand	8,161	56,900	60,487	139,465	278,680	361,237	520,831	562,639
	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF_{fuel}	1							
Petroleum	Total electricity generation	32,071	19,964	18,856	42,045	26,142	17,733	12,878	31,616
	PE demand	103,454	57,040	49,621	105,112	63,760	41,239	29,948	70,257
	Efficiency	31%	35%	38%	40%	41%	43%	43%	45%
	PEF_{fuel}	1							
LNG	Total electricity generation		250	9,604	21,296	28,146	58,118	96,734	100,783
	PE demand		1,136	35,570	78,874	97,055	193,726	312,045	325,106
	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF_{fuel}		1						
Steam	Total electricity generation	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
	PE demand	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
	Efficiency	45%							
	PEF_{fuel}		1						

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Renewables	Total electricity generation	29	23.61	9.26	12.22	24.76	46.04	70.5	149
	PE demand	29	23.61	9.26	12.22	24.76	46.04	70.5	149
	Efficiency	100%							
	PEF $_{fuel}$	1							
	Raw Primary energy demand	157,436	206,911	359,409	621,311	899,172	1,200,591	1,543,169	1,700,507

4.1.2.3. Generation of heat calculations from Combined heat and power plant (CHP)

The heat generated from the CHP has been calculated in table 15. The self- consumption is assumed to be 8%,

Table 11. Calculation of CHP heat generation (GWh)

Name		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
CHP	Electricity generation	258	58	619	20,521	26,863	57,457	94,012	100,598
	Electricity/heat	36%	38%	38%	39%	40%	42%	42%	46%
	1-(Self-Cons)	92%	92%	92%	92%	92%	92%	92%	92%
	Heat generation	659	166	1,498	48,408	61,784	125,858	205,931	201,196

4.1.2.4. Calculations of fuel consumption by CHP

The calculation of fuel consumption for the CHP electricity and heat generation has been shown in table 16.

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Table 12. Calculations of CHP Fuel consumption (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Elec Gen CHP	258	58	619	20,521	26,863	57,457	94,012	100,598
	Heat Gen CHP	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Total output	917	224	2,117	68,929	88,647	183,315	299,943	301,794
	Efficiency	70%	70%	70%	70%	70%	70%	70%	70%
	Fuel consumption	1,310	320	3,025	98,470	126,638	261,878	428,490	431,134

4.1.2.5. Calculations of heat Bonus

The heat bonus for the CHP has been shown in table 17

Table 13. Calculation of heat bonus (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Elec Gen CHP	258	58	619	20,521	26,863	57,457	94,012	100,598
	Heat Gen CHP	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Total output	917	224	2,117	68,929	88,647	183,315	299,943	301,794
	Fuel consumption	1,310	320	3,025	98,470	126,638	261,878	428,490	431,134
	PEF CHP fuel	1	1	1	1	1	1	1	1
	Heat Bonus	941	199	2,140	69,154	88,262	179,796	294,187	287,422

4.1.2.6. Calculations of Primary energy factor of electricity

The Final PEF of electricity generation by Eurostat Methodology has been shown in table 18**.**

Table 14. Final PEF of electricity generation by Eurostat Methodology

	1980	1985	1990	1995	2000	2005	2010	2015
RPED	157,436	206,911	359,409	621,311	899,172	1,200,591	1,543,169	1,700,507
Heat bonus	941	199	2,140	69,154	88,262	179,796	294,187	287,422
Net electricity demand	65,075	85,048	137,441	260,026	373,135	513,765	707,890	772,117
Final PEF	3.07	3.04	3.09	2.59	2.64	2.40	1.96	2.21

4.1.2.7. Contributions to Primary energy factor

The trend and the contribution of each source to the calculation of the PEF of electricity generation have been shown in the fig. 18.

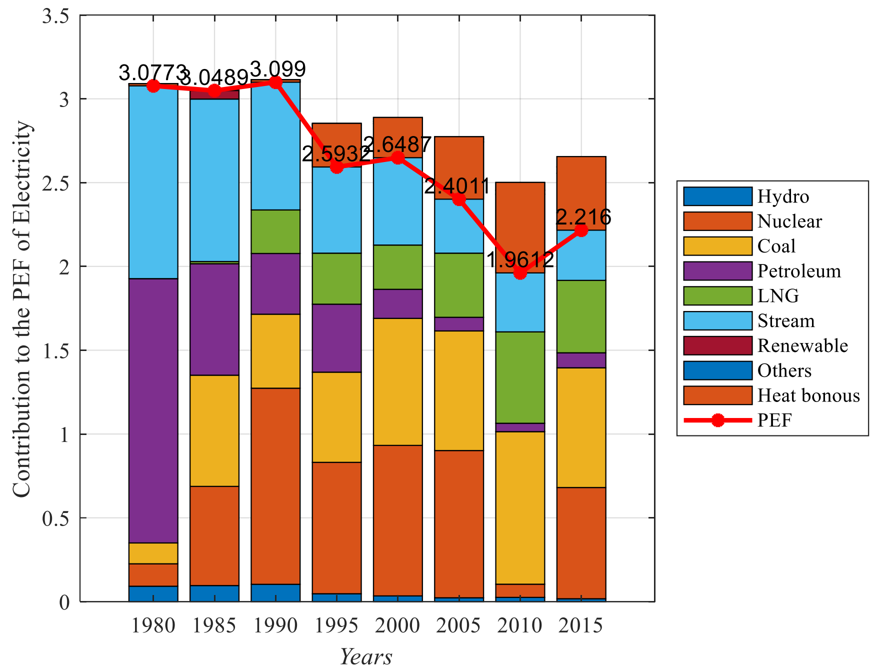

Figure 11. Calculation of Primary energy factor of electricity generation by Eurostat Methodology

As can be seen in the fig. 18 for the Eurostat methodology, the Primary energy factor of electricity increase from the period of 1980 to 1990. The value of the PEF was highest in 1990 and it was 3.099. After 1990, the value of PEF continue to decrease and it reaches at 1.80 in 2015. In the initial years, the Hydropower contributes more to the development of PEF. But in later years, the contribution of coal is more prominent.

4.1.3. Calculations method 2 – Life Cycle Approach

4.1.3.1. Calculations of Raw Primary energy demand

The RPED of the electricity generation for the Life Cycle approach has been shown in table 19.

Table 15. Calculations of RPED by Life cycle approach (GWh)

Source	Factors	1980	1985	1990	1995	2000	2005	2010	2015
Hydro	Total electricity generation	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
	PE demand	162.3	219.5	381	328	336	311	388	347
	Efficiency	45%							
	PEF_{fuel}	0.06							
Nuclear	Total electricity generation	2,897	16,745	52,887	67,029	108,964	146,779	148,596	164,762

	PE demand	8,778	50,742	160,263	203,118	330,193	444,784	450,290	499,278
	Efficiency	33%							
	PEF fuel	1							
Coal	Total electricity generation	2,530	17,639	19,961	48,813	97,538	133,658	197,916	213,803
	PE demand	8,732	60,883	64,722	149,228	298,187	386,524	557,289	602,024
	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF fuel	1.07							
Petroleum	Total electricity generation	32,071	19,964	18,856	42,045	26,142	17,733	12,878	31,616
	PE demand	114,834	63,314	55,079	116,674	70,774	45,775	33,243	77,986
	Efficiency	31%	35%	38%	40%	41%	43%	43%	45%
	PEF fuel	1.11							
LNG	Total electricity generation	-	250	9,604	21,296	28,146	58,118	96,734	100,783
	PE demand	-	1,284	40,194	89,127	109,672	218,911	352,611	367,370
	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF fuel	1.13							
Steam	Total electricity generation	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
	PE demand	2,401	2,618	3,296	6,247	8,396	10,584	14,801	15,146
	Efficiency	45%							
	PEF fuel	0.07							
Renewable	Total electricity generation	2492	2,031	797	1,051	2,130	3,961	6,064	12,839
	PE demand	199	162.4	63.76	84.08	170	316	485	1027
	Efficiency	45%							
	PEF fuel	0.08							
	Raw Primary energy demand	167,010	179,222	323,998	565,964	821,631	1,110,368	1,421,171	1,584,082

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4.1.3.2.Calculations of heat Generation

The heat generated from the CHP has been calculated in table 20. The self- consumption is assumed to be 8%.

Table 16. Calculations of heat generation (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Electricity generation	258	58	619	20,521	26,863	57,457	94,012	100,598
	Electricity/heat	36%	38%	38%	39%	40%	42%	42%	46%
	1-(Self-Cons)	92%	92%	92%	92%	92%	92%	92%	92%
	Heat generation	659	166	1,498	48,408	61,784	125,858	205,931	201,196

4.1.3.3.Calculations of fuel consumption

The calculation of fuel consumption for the CHP electricity and heat generation has been shown in table 21.

Table 17. Calculations of fuel consumption (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Elec Gen CHP	258	58	619	20,521	26,863	57,457	94,012	100,598
	Heat Gen CHP	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Total output	917	224	2,117	68,929	88,647	183,315	299,943	301,794
	Efficiency	70%	70%	70%	70%	70%	70%	70%	70%
	Fuel consumption	1310	320	3,025	98,470	126,638	261,878	428,490	431,134

4.1.3.4.Calculations of process efficiencies

The life cycle approach uses the Finnish method for CHP evaluation. The efficiencies of electricity and heat generation for the CHP has been shown in table 22.

Table 18. Calculations of efficiencies process

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Heat gen.	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Fuel Cons.	1310	320	3,025	98,470	126,638	261,878	428,490	431,134
	Efficiency	50%	51%	49%	49%	48%	48%	48%	46%
	Elect. gen	258	58	619	20,521	26,863	57,457	94,012	100,598
	Fuel Cons	1,310	320	3,025	98,470	126,638	261,878	428,490	431,134
	Efficiency	19%	18%	20%	20%	21%	21%	22%	23%

4.1.3.5.Calculations of ratio of efficiencies compared to the alternative reference system

Table 23 compared the ratio efficiencies compared to the alternative reference system

Table 19. Calculations of ratio efficiencies compared to the alternative reference system

Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP eff. Elect.	19%	18%	20%	20%	21%	21%	22%	23%
Ref. eff. Elec.	40%	40%	40%	40%	40%	40%	40%	40%
Ratio eff.	47.5 %	45%	50%	50%	52%	52%	55%	57%
CHP eff. Heat	50%	51%	49%	49%	48%	48%	48%	46%
Ref. eff. Heat	90%	90%	90%	90%	90%	90%	90%	90%
Ratio eff.	55%	56%	54%	54%	53%	53%	53%	51%
Sum of ratio eff.	102.5	101%	104%	104%	105%	105%	108%	108%

4.1.3.6.Calculations of the efficiency factor

The efficiency factor for the life cycle approach has been shown in table 24.

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Table 20. Calculations of eiciency factor (GWh)

CHP	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Sum of ratio eff.	1.02	1.01	1.04	1.04	1.05	1.05	1.08	1.08
	Efficiency factor (1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%

4.1.3.7.Calculations of heat bonus

The calculations of heat bonus for the CHP system has been shown in table 25.

Table 21. Calculations of heat Bonus (GWh)

	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP	Fuel cons.	1,310	3,200	3,025	98,470	126,638	261,878	428,490	431,134
	Ratio reff. Heat	55%	56%	54%	54%	53%	53%	53%	51%
	(1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%
	PEF fuel	1.07	1.06	1.04	1.03	1.02	1.02	1.01	1.01
	Heat bonus	755	1,880	1,727	52,578	65,037	134,492	211,021	204,310

4.1.3.8.Calculations of primary energy factor of electricity

Table 26 shows the final PEF of electricity generation by the life cycle approach.

Table 22. Calculation of PEF of electricity generation by Life Cycle Approach

	1980	1985	1990	1995	2000	2005	2010	2015
RPED	167,012	179,222	323,998	565,964	821,631	1,110,368	1,421,171	1,584,082
Heat bonus	755	1,880	1,727	52,578	65,037	134,492	211,021	204,310

Net electricity demand	67,758	86,026	137,441	260,026	373,135	513,765	707,890	772,117
Final PEF	2.10	2.13	2.39	2.13	2.18	2.10	1.62	1.93

4.1.3.9.Contribution to PEF

The trend and the contribution of each source to the calculation of the PEF of electricity generation has been shown in the fig. 19.

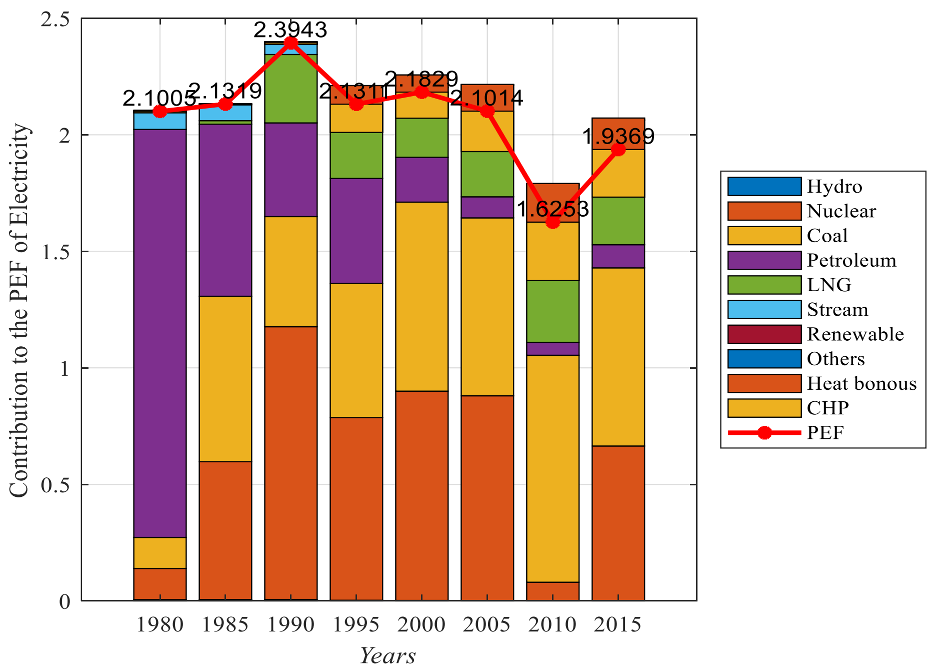

Figure 12. Calculation of PEF of electricity generation

For the LCA approach, As it can be seen in the fig. 19, the Primary energy factor of electricity increase from the period of 1980 to 1990. The value of the PEF was highest in 1990 and it was 2.39. After 1990, the value of PEF continue to decrease till 2010 and it reaches at 1.62 in 2015. In the initial years, the Hydropower contributes more to the development of PEF. But in the later years, the contribution of coal is more prominent.

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4.1.4. Calculation method 3 – Modified Eurostat Methodology

4.1.4.1.Generation of heat calculation from Combined heat and power plant

The heat generated from the CHP has been calculated in table 27. The self- consumption is assumed to be 8%.

Table 23. Calculation of CHP heat generation (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Electricity generation	258	58	619	20521	26863	57457	94012	100598
	Electricity/heat	36%	38%	38%	39%	40%	42%	42%	46%
	1-(Self-Cons)	92%	92%	92%	92%	92%	92%	92%	92%
	Heat generation	659	166	1,498	48,408	61,784	125,858	205,931	201,196

4.1.4.2.Calculation of fuel consumption by CHP

The calculation of fuel consumption for the CHP electricity and heat generation has been shown in table 28.

Table 24. Calculation of CHP Fuel consumption (GWh)

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Elec Gen CHP	258	58	619	20,521	26,863	57,457	94,012	100,598
	Heat Gen CHP	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Total output	917	224	2,117	68,929	88,647	183,315	299,943	301,794
	Efficiency	70%	70%	70%	70%	70%	70%	70%	70%
	Fuel consumption	1,310	320	3,025	98,470	126,638	261,878	428,490	431,134

4.1.4.3.Calculation of process efficiencies

The modified Eurostat methodology uses the Finnish method for the CHP evaluation. The efficiencies of electricity and heat generation for the CHP has been shown in table 29.

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Table 25. Calculations of CHP efficiencies of electricity and heat generation

Name		1980	1985	1990	1995	2000	2005	2010	2015
CHP	Heat gen.	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Fuel Cons.	1310	320	3025	98470	126638	261878	428,490	431,134
	Efficiency	50%	51%	49%	49%	48%	48%	48%	46%
	Elect. gen	258	58	619	20521	26863	57457	94012	100598
	Fuel Cons	1310	320	3025	98470	126638	261878	428490	431134
	Efficiency	19%	18%	20%	20%	21%	21%	22%	23%

4.1.4.4.Calculations of ratio of efficiencies compared to the alternative reference system

The table 30. Compared the ratio efficiencies compared to the alternative reference system.

Table 26. Calculations of ratio efficiencies compared to the alternative reference system

Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP eff. Elect.	19%	18%	20%	20%	21%	21%	22%	23%
Ref. eff. Elec.	40%	40%	40%	40%	40%	40%	40%	40%
Ratio eff.	47.5 %	45%	50%	50%	52%	52%	55%	57%
CHP eff. Heat	50%	51%	49%	49%	48%	48%	48%	46%
Ref. eff. Heat	90%	90%	90%	90%	90%	90%	90%	90%
Ratio eff.	55%	56%	54%	54%	53%	53%	53%	51%
Sum of ratio eff.	102.5	101%	104%	104%	105%	105%	108%	108%

4.1.4.5.Calculations of the efficiency factor

The efficiency factor for the modified Eurostat methodology has been shown in table 31

Table 27. Calculations of efficiency factor

CHP	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Sum of ratio eff.	1.02	1.01	1.04	1.04	1.05	1.05	1.08	1.08
	Efficiency factor (1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%

4.1.4.6. Calculation of heat bonus

The calculations of heat bonus for the CHP system has been shown in table 32.

Table 28. Calculations of heat bonus

Fuel	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP	Fuel cons.	1310	3200	3025	98470	126638	261878	428490	431134
	Ratio reff. Heat	55%	56%	54%	54%	53%	53%	53%	51%
	(1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%
	PEF fuel	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Heat bonus	706	1,774	1,568	51,046	63,762	131,855	208,931	202,288

4.1.4.7. Calculation of primary energy factor of electricity

Table 33 shows the final PEF of electricity generation by the life cycle approach.

Table 29. Calculations of Final PEF of electricity by modified Eurostat methodology

	1980	1985	1990	1995	2000	2005	2010	2015
RPED	157,436	206,911	359,409	621,311	899,172	1,200,591	1,543,169	1,700,507
Heat bonus	706	1,774	1,568	51,046	63,762	131,855	208,931	202,288

Net electricity demand	67,758	86,026	137,441	260,026	373,135	513,765	707,890	772,117
Final PEF	3.08	3.05	3.10	2.76	2.80	2.64	2.31	2.50

4.1.4.8.Contribution to PEF

The trend and the contribution of each source to the calculation of the PEF of electricity generation have been shown in the fig. 20.

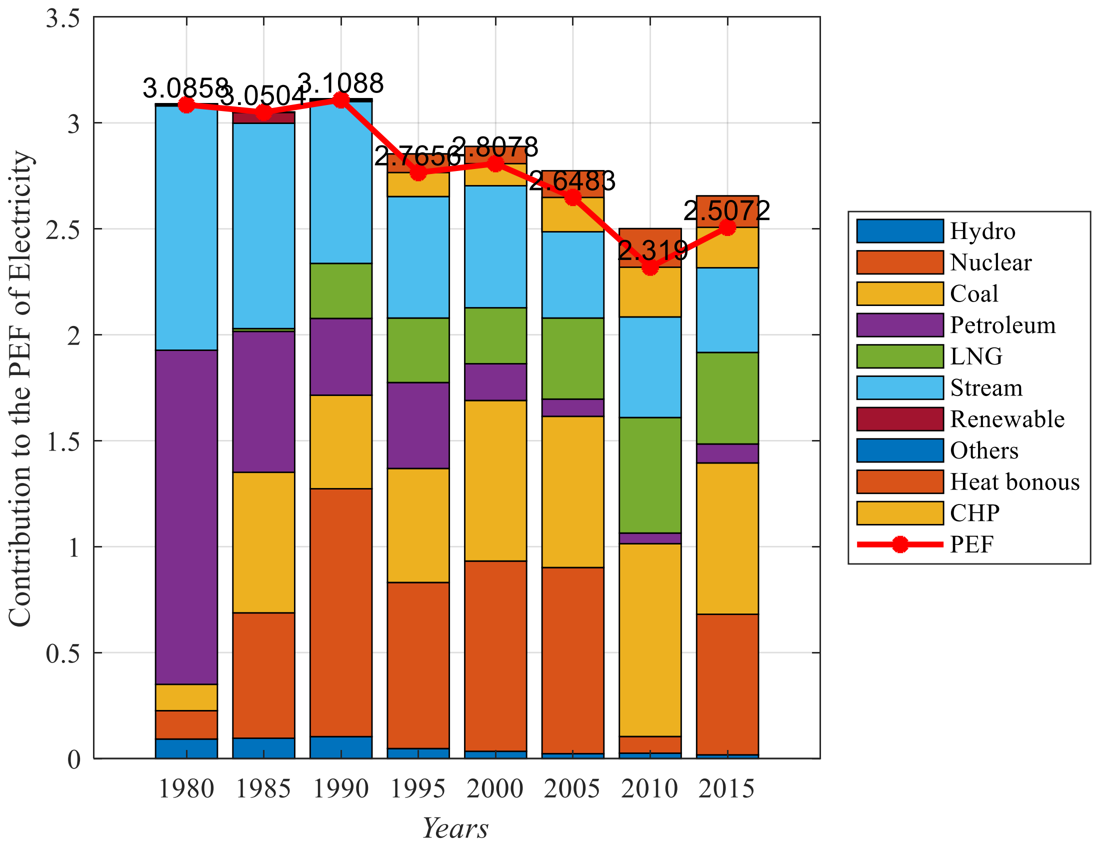

Figure 13. Contribution of energy sources to the development of PEF of electricity.

As can be seen in figure 20, for the Modified Eurostat methodology, the Primary energy factor of electricity increase from the period of 1980 to 1990. The value of the PEF was highest in 1990 and it was 3.10. After 1990, the value of PEF continues to decrease and it reaches at 2.50 in 2015. In the initial years, the Hydropower contributes more to the development of PEF. But in later years, the contribution of coal is more prominent. The basic difference between the Eurostat and Modified Eurostat Methodology that the Modified Eurostat methodology uses the Finnish method for the CHP analysis unless the IEA method in Eurostat methodology.

4.1.5. Calculation method 4 – Upper-end Method

4.1.5.1.Calculation of Raw Primary energy demand

The RPED of the electricity generation for the Upper-end methodology has been shown in table 34.

Table 30. Calculations of RPED by upper-end methodology

Source	Factors	1980	1985	1990	1995	2000	2005	2010	2015
Hydro	Total electricity generation	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
	PE demand	2,709	3,659	6,361	5,478	5,610	5,189	6,472	5,796
	Efficiency	45%							
	PEF $_{fuel}$	1							
Nuclear	Total electricity generation	2,897	16,745	52,887	67,029	108,964	146,779	148,596	164,762
	PE demand	8,778	50,742	160,263	203,118	330,193	444,784	450,290	499,278
	Efficiency	33%							
	PEF $_{fuel}$	1							
Coal	Total electricity generation	2,530	17,639	19,961	48,813	97,538	133,658	197,916	213,803
	PE demand	9,059	63,159	71,473	154,806	309,334	400,974	578,123	624,529
	Efficiency	31%	31%	33%	35%	35%	37%	38%	38%
	PEF $_{fuel}$	1.11							
Petroleum	Total electricity generation	32,071	19,964	18,856	42,045	26,142	17,733	12,878	31,616
	PE demand	114,834	63,314	55,079	116,674	70,774	45,775	33,243	77,986
	Efficiency	31%	35%	38%	40%	41%	43%	43%	45%
	PEF $_{fuel}$	1.11							

LNG	Total electricity generation		250	9,604	21,296	28,146	58,118	96,734	100,783
	PE demand		1,261	39,483	87,550	107,731	215,036	346,370	360,868
	Efficiency	21%	22%	27%	27%	29%	30%	31%	31%
	PEF_{fuel}		1.11						
Steam	Total electricity generation	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
	PE demand	34,305	37,411	47,098	89,252	119,947	151,207	211,449	216,378
	Efficiency	45%							
	PEF_{fuel}		1						
Renewable	Total electricity generation	29	23.61	9.26	12.22	24.76	46.04	70.5	149
	PE demand	29	23.61	9.26	12.22	24.76	46.04	70.5	149
	Efficiency	45%							
	PEF_{fuel}	1							
	Raw Primary energy demand	169,714	219,569	379,766	656,890	947,516	1,266,174	1,638,081	1,805,888

4.1.5.2.Generation of heat calculation from Combined heat and power plant

The heat generated from the CHP has been calculated in table 35. The self- consumption is assumed to be 8%,

Table 31. Calculation of heat generation

Name		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
	Electricity generation	258	58	619	20,521	26,863	57,457	94,012	100,598
	Electricity/heat	36%	38%	38%	39%	40%	42%	42%	46%

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CHP	1-(Self-Cons)	92%	92%	92%	92%	92%	92%	92%	92%
	Heat generation	659	166	1,498	48,408	61,784	125,858	205,931	201,196

4.1.5.3.Calculation of fuel consumption

The calculation of fuel consumption for the CHP electricity and heat generation has been shown in table 36.

Table 32. Calculation of fuel Consumption

Name		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
CHP	Elec Gen CHP	258	58	619	20,521	26,863	57,457	94,012	100,598
	Heat Gen CHP	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Total output	917	224	2,117	68,929	88,647	183,315	299,943	301,794
	Efficiency	70%	70%	70%	70%	70%	70%	70%	70%
	Fuel consumption	1310	320	3,025	98,470	126,638	261,878	428,490	431,134

4.1.5.4.Calculation of process efficiencies

The upper-end methodology uses the Finnish method for the CHP evaluation. The efficiencies of electricity and heat generation for the CHP has been shown in table 37.

Table 33. Calculation of process efficiencies

Name		**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
CHP	Heat gen.	659	166	1,498	48,408	61,784	125,858	205,931	201,196
	Fuel Cons.	1310	320	3,025	98,470	126,638	261,878	428,490	431,134
	Efficiency	50%	51%	49%	49%	48%	48%	48%	46%
	Elect. gen	258	58	619	20,521	26,863	57,457	94,012	100,598
	Fuel Cons	1,310	320	3,025	98,470	126,638	261,878	428,490	431,134
	Efficiency	19%	18%	20%	20%	21%	21%	22%	23%

4.1.5.5.Calculations of ratio of efficiencies compared to the alternative reference system

The table 38. Compared the ratio efficiencies compared to the alternative reference system

Table 34. Calculations of ratio efficiencies compared to the alternative reference system

Name	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
	CHP eff. Elect.	19%	18%	20%	20%	21%	21%	22%	23%
	Ref. eff. Elec.	40%	40%	40%	40%	40%	40%	40%	40%
	Ratio eff.	47.5 %	45%	50%	50%	52%	52%	55%	57%
	CHP eff. Heat	50%	51%	49%	49%	48%	48%	48%	46%
	Ref. eff. Heat	90%	90%	90%	90%	90%	90%	90%	90%
	Ratio eff.	55%	56%	54%	54%	53%	53%	53%	51%
	Sum of ratio eff.	102.5	101%	104%	104%	105%	105%	108%	108%

4.1.5.6.Calculations of the efficiency factor

The efficiency factor for the life cycle approach has been shown in table 39.

Table 35. Calculations of efficiency factor

Name	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Sum of ratio eff.	1.02	1.01	1.04	1.04	1.05	1.05	1.08	1.08
	Efficiency factor (1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%

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4.1.5.7. Calculation of heat bonus

The calculations of heat bonus for the CHP system has been shown in table 40.

Table 36. Calculations of heat bonus

Fuel	Indicator	1980	1985	1990	1995	2000	2005	2010	2015
CHP	Fuel cons.	1,310	3,200	3,025	98,470	126,638	261,878	428,490	431,134
	Ratio reff. Heat	55%	56%	54%	54%	53%	53%	53%	51%
	(1-PEE)	98%	99%	96%	96%	95%	95%	92%	92%
	PEF fuel	1.10	1.10	1.09	1.09	1.09	1.08	1.07	1.07
	Heat bonus	778	1,951	1,710	55,641	69,500	142,404	223,557	216,448

4.1.5.8.Calculation of primary energy factor of electricity

Table 41 shows the final PEF of electricity generation by upper-end methodology.

Table 37. Calculations of final PEF of electricity

	1980	1985	1990	1995	2000	2005	2010	2015
RPED	169,714	219,569	379,766	656,890	947,516	1,266,174	1,638,081	1,805,888
Heat bonus	778	1,951	1,710	5,5641	69,500	142,404	223,557	216,448
Net electricity demand	67,758	86,026	137,441	260,026	373,135	513,765	707,890	772,117
Final PEF	3.26	3.17	3.21	2.89	2.92	2.77	2.48	2.64

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4.1.5.9.Contribution to PEF

The trend and the contribution of each source to the calculation of the PEF of electricity generation has been shown in the fig. 21.

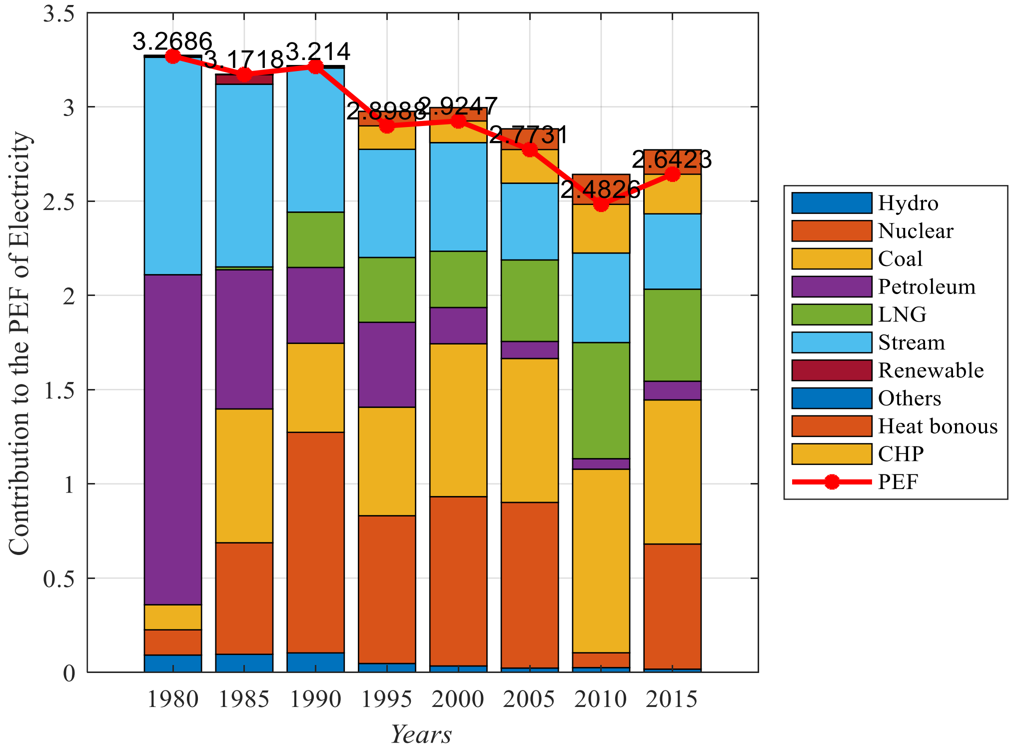

Figure 14. Calculations of PEF of electricity by the upper-end method

As can be seen in figure 21, for the upper-end methodology, the Primary energy factor of electricity increase from the period of 1980 to 1990. The value of the PEF was highest in 1990 and it was 3.21. After 1990, the value of PEF continues to decrease and it reaches 2.48 in 2010 and slightly increase in 2015 to 2.64. In the initial years, the Hydropower contributed more to the development of PEF. But in the later years, the contribution of coal was more prominent.

4.1.6. Comparison of all four methods

The Comparison of all the four methods has been shown in Figure 22

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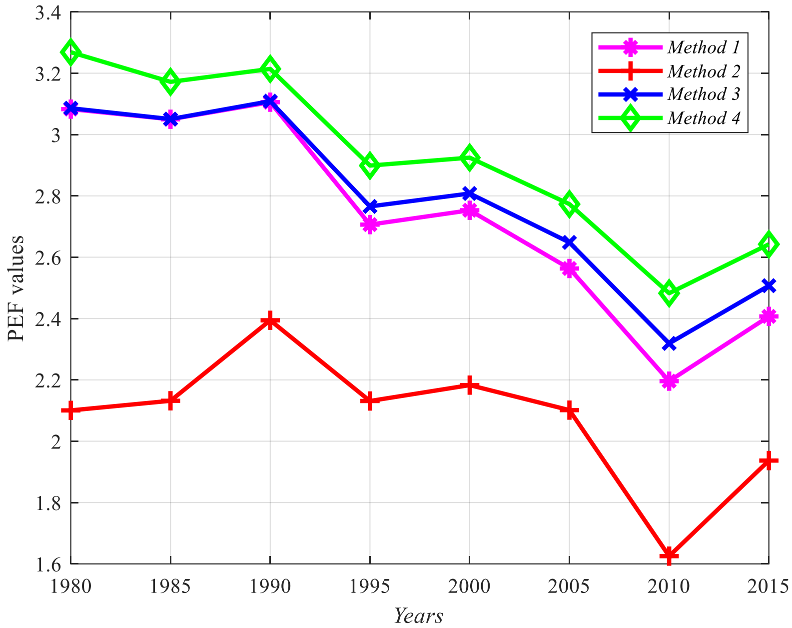

Figure 15. Comparison of methods for the development of PEF of electricity

As can be seen in Figure 22, that the LCA methodology has the lowest value trend of PEF of electricity. The maximum value of PEF in case of LCA methodology was 2.36. The Upper-end method has the highest value trend of PEF. For the non-renewable sources, it considers the LCA methodology and taking into account the entire supply chain. In all the four methods, the PEF values of electricity have been decreasing and increase slightly at the end.

4.1.7. Future Trends of PEF

The future trend of the PEF of electricity generation has been shown in figure 23.

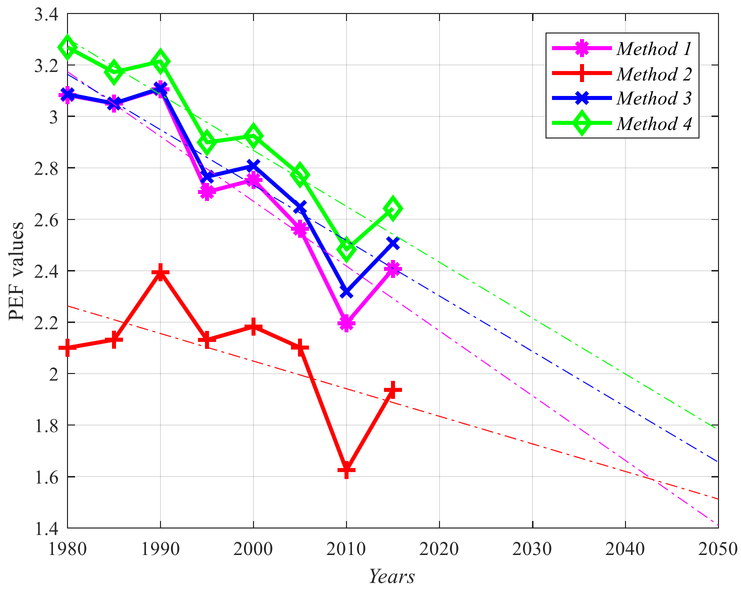

Figure 16. Future Trend of PEF of electricity

For all the methods, the PEF of electricity is going to decrease. The PEF of electricity generation in 2030 will be around 1.90 and 2.10 according to Eurostat and modified Eurostat methodology. For the LCA and the upper end, the PEF of electricity generation will be around 1.70 and 2.20 respectively.

For the year 2040, the PEF of electricity generation will be around 1.65 and 1.90 according to Eurostat and modified Eurostat methodology. For the LCA and the upper-end methodology, the PEF of electricity generation will be around 1.60 and 2.00 respectively.

For the year 2050, the PEF of electricity generation will be around 1.40 and 1.60 according to Eurostat and modified Eurostat methodology. For the LCA and the upper-end methodology, the PEF of electricity generation will be around 1.50 and 1.80 respectivel23

4.1.8. Recommended PEF values of electricity generations for policymaking

The fig. 24 shows the recommended values of PEF of electricity generation in South Korea for Policy making.

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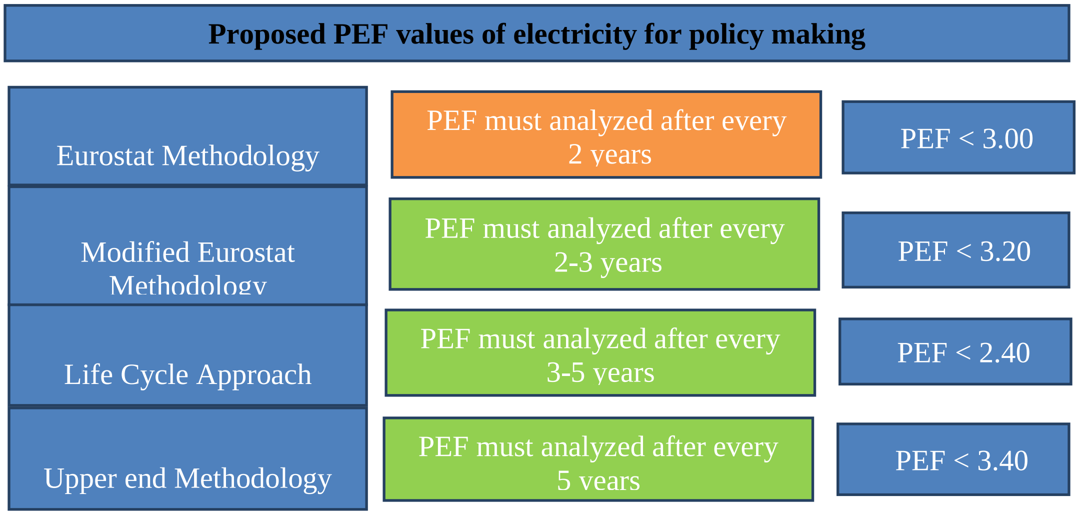

Figure 17. Optimized values of PEF of electricity generations

For the Eurostat methodology, the recommended value of PEF must be less than 3 and it must be analyzed every 2 years. For the Modified Eurostat methodology, the recommended value of PEF must be less than 3.20 and it must be analyzed with 2-3 years. The PEF of electricity calculated through the Life Cycle approach must be less than 2.40 and it must be analyzed with 3-5 years. The upper-end method provides the highest value of PEF and it must be analyzed after every 5 years. Its value must be less than 3.40. In the policymaking, it must be confirmed that any energy source imported to generate electricity in South Korea does not raise the threshold value of the PEF of electricity recommended for each method.

5. Conclusion

The PEF of electricity were calculated using 4 different methodologies

- Eurostat Methodologies
- Life cycle approach
- Modified Eurostat Methodologies
- Upper-end method

The Eurostat methodology considers the conversion and transmission portion only and calculates the total PEF, whereas the Life cycle method considers the entire supply chain and calculate only the non-renewable portion of PEF. The basic difference between Eurostat and modified Eurostat methodology is the method of evaluating electricity generation from the CHP plant. The Eurostat methodology uses the IEA method and the Modified Eurostat methodology use the Finnish method to evaluate the electricity generation from CHP. The upper-end method sets the upper limit of calculating PEF and calculate total PEF. In all the four methods, the PEF of electricity shows the decreasing trend. The upper-end method showed the highest values trend of PEF and the lowest values trend was calculated using the Life cycle approach. It has been extrapolated that in 2050, the PEF values of electricity would be 1.4 and 1.6 according to Eurostat and modified Eurostat methodology respectively. According to the Life cycle and upper-end methodology, the PEF values of electricity will be 1.5 and 1.8 respectively.

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