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COIMBRA

Maurício Amorim Aleixo Gonçalves

Primary Energy Factors and Specific Emissions for the Portuguese Network

Dissertation within the Integrated Master's Degree in Electrical and Computer Engineering, Specialization in Energy, supervised by Professor Doctor Humberto Manuel Matos Jorge and Professor Doctor Pedro Manuel Soares Moura and presented to the Department of Electrical and Computer Engineering of the Faculty of Sciences and Technology of the University of Coimbra

September 2019

Faculty of Sciences and Technology
Department of Electrical and Computer Engineering

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“*Sustainability is not just about adopting the latest energy-efficient technologies or turning to renewable sources of power. Sustainability is the responsibility of every individual every day. It is about changing our behavior and mindset to reduce power and water consumption, thereby helping to control emissions and pollution levels.”*

Joe Kaeser, CEO of Siemens AG

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ABSTRACT

In the context of the world we live in today, where climate change is a problem, and being directly related to CO_2 emissions, it is important, especially for Portugal, to change the paradigm of many years of using fossil fuels (these also related to emissions to the atmosphere). There are plenty of options for renewable energy sources in this country, and some data say that renewable energy production has already surpassed fossil fuel production.

Conversion factors for primary energy and specific greenhouse gas emissions are based on average values despite the primary energy and vary strongly with the seasons and the time of day due to the renewable generation. Additionally, in most countries, these are out of date. due to the recent evolution of the generation mix. Recent studies have been analyzing and proposing different methodologies in order to determine primary energy factors. It is thus intended, in this study, to determine based on some of these methodologies, and taking based on data from the Portuguese power grid in recent years, the primary energy factors and specific CO_2 emissions from the Portuguese electricity network. It is also intended to analyze its variation throughout the year (month and seasons) and the time of the day.

Through the study and the applications made in this dissertation it was possible to verify what was previously said, and, in fact, the PEF value, besides being outdated, is decontextualized, as this value varies with the seasons of the year and also with the contribution and production through renewable sources, which, as also been verified, is directly related to this value. With the methods used a value of 1.87 was obtained based on the last years, and since the value that is used today is 2.5 it can be noticed that many other factors that depend on PEF are wrong. Another factor calculated here was that of CO_2 emissions, which is once again directly related to PEF since with the increase in emissions there is a higher PEF, thus indications of strong production in fossil fuels. Therefore, based on this work, it can be stated that the value of the primary energy factor has to be constantly monitored in order to be able to make correct predictions as well as not to induce other calculations, such as product efficiency, in error.

Key-words: Primary Energy: Primary Energy Factor; CO_2 Emissions; Emission Factor; Renewable Energy Source; Electricity Generation.

RESUMO

No enquadramento do mundo em que vivemos atualmente, em que as alterações climáticas são uma problemática, e estando estas diretamente relacionadas com as emissões de CO_2, é importante, principalmente para Portugal, mudar o paradigma de muitos anos em usar energias fósseis (estes também relacionados com as emissões para a atmosfera). As variadas opções que este país tem em termos de fontes de energia renovável são imensas, e a verdade é que certos dados afirmam que a produção através de energia renovável já ultrapassou a produção através de combustíveis fósseis.

Os fatores de conversão para a energia primária e as emissões específicas de gases de efeito estufa são baseados em valores médios, apesar da energia primária e as emissões especificas variarem fortemente com a época do ano e a hora do dia, devido à variação da geração renovável. Adicionalmente, na maioria dos países estes estão desatualizados devido à evolução recente do mix de geração. Estudos recentes têm vindo a analisar e propor diferentes metodologias para determinar os Fatores de Energia Primária (PEF). Pretende-se assim determinar, com base em algumas dessas metodologias, e tendo como base os dados da rede portuguesa dos últimos anos, os PEF e das emissões específicas da rede portuguesa. Pretende-se também analisar a sua variação ao longo do ano e em função da hora do dia.

Através do estudo e das aplicações feitas nesta dissertação foi possível verificar o que anteriormente foi dito, e, de facto, o valor de PEF, para além de estar desatualizado, está descontextualizado, pois este valor varia com as estações do ano e também variam com a contribuição e a produção através das renováveis, que, como também verificado, está diretamente relacionado com este valor. Com os métodos usados foi obtido um valor de 1.87, com base nos últimos anos, e visto que o valor que é utilizado atualmente é de 2.5 pode-se reparar que muitos outros fatores, que dependem do PEF, estão errados. O fator de emissões de CO_2, que mais uma vez está diretamente relacionado com o PEF, visto que com o aumento das emissões temos um PEF maior, logo indícios de uma produção acentuada nos combustíveis fósseis. Portanto, com base neste trabalho, pode-se afirmar que o valor do fator de energia primária tem de ser constantemente monitorizado de maneira a poder fazer previsões corretas assim como não induzir outros cálculos, como os da eficiência dos produtos, em erro.

Palavras-chave: Energia primária: Fator de energia primária; Emissões de CO_2; Fator de emissão; Energia renovável; Geração elétrica.

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ACRONYMS

η – Primary energy conversion efficiency

A – Coefficient of activity

APA – Agência Portuguesa do Ambiente

APREN – Associação Portuguesa de Energias Renováveis

CEWEP – Confederation of European Waste-to-Energy Plants

CF – Calorific value

CFC – Chlorofluorocarbon

CHP – Combined heat and power

DE – Direct equivalent

DGEG – Direção-Geral de Energia e Geologia

EE – Electric energy

EEA- European Union Agency

EED – Energy Efficiency Directive

EF – Emission factor (CO_2 equivalent)

EP – Energy production

EU – European Union

GEMIS – Global emissions model for integrated systems

GHG – Greenhouse gases

IEA – International Energy Agency

IINAS – International Institute for Sustainability Analysis and Strategy

LCA – Life cycle assessments

LULUCF - Land use change and forestry

MSW – Municipal solid wastes

NR – Non-renewable

OECD – Organisation for Economic Co-operation and Development

PE – Primary energy

PEC – Physical energy content

PEF – Primary energy factor

PNAC - Programa Nacional para as Alterações Climáticas

PV – Photovoltaic

R – Renewable

REN – Redes Energéticas Nacionais

RES – Renewable energy sources

RNT – National transmission network

TCE – Technical conversion efficiencies

TE – Thermal

UE – Useful energy

1. INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

As Mário Guedes, former Director-General of Energy and Geology, said, the energy base of the world economy has long been based on fossil energies, initially coal and later oil and natural gas, raw materials whose occurrence in the national territory has always been quite scarce, with some exceptions. This absence of natural energy sources caused the loss of the front carriages of the second industrial revolution train.

In the 1970s, western economies began to realize the enormous environmental impacts of ecosystems and climate change caused by the high atmospheric emissions of CO_2, NO_X, SO_2, CFCs and others. At the same time, the economy was devastated by the effects of oil leading several countries to seek the application of “cleaner” technologies using alternative sources such as sun and wind. Initially, the production of electricity through renewable sources presents competitiveness difficulties, resulting in the existence of subsidies, namely through guaranteed tariffs, a situation that, with the technological advancements that occurred, became less and less necessary.

In 2017, the national fossil fuel energy dependency decreased to 78.3%, compared to 89.6% in 1995. This reduction is explained by the increase in hydro and mainly wind production, which will be fast-forwarded with the future entry into production of solar power plants.

The focus on endogenous renewable energy is an essential and priority option in the fight against national fossil fuel energy dependence, capable of inducing the competitiveness of the Portuguese economy. This strategy also allows Portugal to share responsibility for combating climate change and preserving ecosystems, as well as reducing the price of energy for the consumer.

With the production of energy comes other burdens, as stated here, emissions of polluting gases are a matter of concern in today's society. There are outdated values that are required to calculate emissions and to work on primary energy issues. Such as Primary Energy Factor (PEF) and CO_2 Emission Factor (EF). The motivations in this paper come from the fact that the Primary Energy Factor has an impact on:

-How countries calculate the energy that they can save;

-How energy-efficient the building stock is perceived to be;

-The competitiveness between technologies in the market, in particular in the heating and electricity sector;

-Which energy label class is achieved by energy-using products - the class achieved is expected to directly affect product sales.

What's the problem with the Primary Energy Factor? The fact that the European power sector is decarbonizing needs to be reflected in the PEF, thus justifying its reduction. Specifically, the PEF impacts several pieces of legislation of which it is part:

- In the Energy Efficiency Directive (EED) it is incentivized the saving in electricity over direct fossil savings to meet the targets.

- The PEF of 2.5 misrepresents the efficiency of electricity in EcoDesign legislation. With a lower PEF, heat pumps, as the most efficient heating technology, would lead over fossil alternatives by an even bigger margin, and other electricity using products would become more competitive.

- The current PEF methodology is outdated and needs a review.

Emission factors have been a key tool in the development of national, regional, state and local inventories for air quality management decisions and the development of use control strategies. However, there are also problems like with PEF uncertainty because it depends on the type of emission released, the number of tests used to determine the emission factor or the appropriate decision level (or percentile) within the distribution range and the number of units of similar use in a specific area.

1.2. Objective

Conversion factors for primary energy and specific greenhouse gas emissions are based on average values despite the primary energy and vary strongly with the seasons and the time of day due to the renewable generation. Additionally, in most countries, these are out of date. due to the recent evolution of the generation mix. Recent studies have been analyzing and proposing different methodologies in order to determine primary energy factors. It is thus intended, in this study, to determine based on some of these methodologies, and taking based on data from the Portuguese power grid in recent years, the primary energy factors and specific CO_2 emissions from the Portuguese electricity network. It is also intended to analyze its variation throughout the year (month and seasons) and the time of the day.

1.3. DISSERTATION STRUCTURE

This dissertation is organized in 7 main chapters. Chapter 1 is dedicated to an introduction of this work and followed by the associated problems faced, in relation to gas emissions and outdated factors. The motivation for the elaboration of this dissertation and its objectives. Chapter 2 is intended to continue the introduction with a more detailed analysis of the primary energy factor and its problems. Chapter 3 presents the Methods to calculate the primary energy factor (PEF). In Chapter 4 the Portuguese case in terms of energy production and consumption is analyzed. Chapter 5 presents the methods and materials to analyze the behavior of energy production and the emission factor. Chapter 6 will then present the main results and their discussion. Chapter 7 will present the main conclusions of this work, and some suggestions for future work.

2. PRIMARY ENERGY FACTOR

2.1. DEFINITION AND CONTEXTUALIZATION

According to Adapt Consulting (2016), a primary energy factor (PEF) is defined by the ratio between the primary energy consumption and the final electricity consumption. The European Union, in particular, has been implementing the regular use of primary energy factors in energy policy actions. Therefore, in Europe, the present values of PEFs have a role in the regulation of generation and consumption of electricity.

The PEF is a variable to be taken into account when calculating the value of energy efficiency since it indicates the total primary energy that is needed to ensure a specific final energy unit. In this it is included as the first step, the extraction of energy, then its transport, then storage and distribution, and finally the delivery and, of course, the associated losses after all previous processes, as shown in Figure 2.1. All this is explained by Wilby et al. (2014) who still conclude that PEFs are a mirror of a complete energy system, from generation to final consumption.

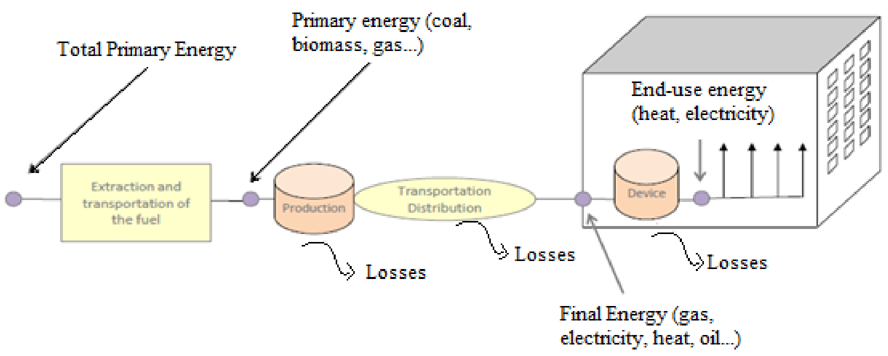

Figure 2.1- Process from Primary Energy to End-Use energy (simplified) adapted from Perraudin (2013).

To calculate the total energy consumption, primary energy factors, also known as conversion factors, are used. These include the total power generation chain based on the final energy consumption data. For the different types of energy, a primary energy factor is assigned, which can identify all the relevant energy demand from the initial generation to the point of energy delivery. These were created allow a comparison between the amount of primary energy needed to deliver a secondary energy unit. However, since countries may have varied ways of functioning from production to delivery, PEFs can vary significantly between countries (Fritsche and Greß 2015).

In order to analyze the life cycle of the energy and to have a database, GEMIS (IINAS 2014a) is introduced. This model assesses the environmental impacts of energy, material and transport systems, but also determines costs and employment balances. GEMIS is used in the countries of the European Union and Organisation for Economic Co-operation and Development (OECD) and Central / Eastern Europe. The software is in the public domain and updated regularly. The most prominent part of GEMIS is the database.

The GEMIS Model calculates all primary energy inputs during their life cycles to determine the PEF, for this it takes into account the extraction of resources as well as the transportation and the respective conversion of energy carriers, the use of fuels and the auxiliary use of energy, and finally the necessary materials that lead to the construction of all the systems that are clustered in this cycle. This is simply explained in Figure 2.2.

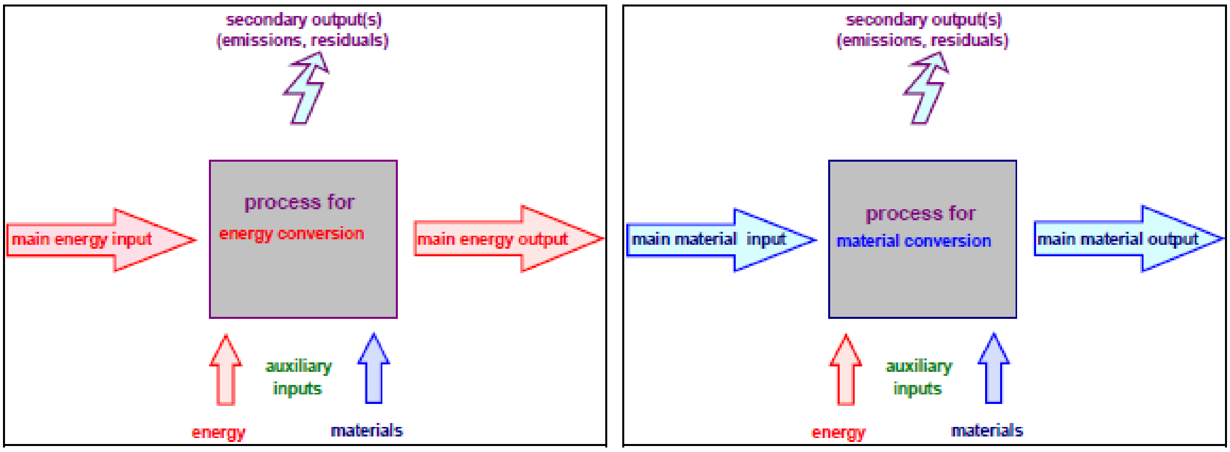

Figure 2.2- Unit processes for energy and materials conversion.

In order to be able to observe the PEFs variation, the EU-28 electricity generation mix in the years 2011 to 2013, based on EUROSTAT (2015) was used. Table 2.1 presents the data collected and using the newly updated GEMIS database, the results for the PEF were calculated and are presented in Table 2.2.

Table 2.1- Electricity Generation Mix (all values in TWh) on the EU-28, 2011-2013, adapted from Fritsche and Greß (2015).

Energy Source (TWh)	2011	2012	2013
Coal	497	545	528
Lignite	344	347	333
Oil	86	85	73
Gas	731	612	538
Nuclear	907	882	877
Wastes (Non-renewable)	20	20	21
Hydro, tidal	312	336	371
Geothermal	6	6	6
Solar -PV	45	67	81
Solar-Thermal	2	4	4
Wind	180	206	235
Biogas	38	46	53
Bioliquids	3	4	4
Solid Biomass	74	80	82
Wastes (Renewable)	18	19	19
Other	35	38	38
Total	**3297**	**3298**	**3261**

Table 2.2- Electricity Generation Mix on the EU-28, 2011-2013, adapted from Fritsche and Greß (2015).

PEF (kWh_{prim}/kWh_{el})	PEF-Total	PEF non-renewable	PEF renewable	PEF other*
2010	2.49	2.18	0.28	0.04
2011	2.51	2.18	0.29	0.04
2012	2.49	2.12	0.32	0. 04
2013	2.46	2.06	0.36	0.04

Source: IINAS computation with GEMIS 4.9; *=includes waste heat, and non-renewable wastes

Analyzing Table 2.2, it is concluded that the total PEF in terms of primary energy per unit of electricity generated decreased from 2011 to 2013. This situation results from the fact that there is an increase in the generation of renewable electricity that has a low PEF. (Fritsche and Greß 2015)

The value attributed to the PEF is 2.5 for electricity from conventional fossil fuels, but the value changes to a different PEF for the renewable energy sources and depends on the method used, which will be presented far ahead. Studies estimate that the PEF values will be 2.05, 1.65 and 1.2 in the year of 2020, 2030 and 2050 (EU-28), respectively (Surmeli-Anac et al. 2014).

2.2. PROBLEMS

It is not necessary to go very far in time to note that there are some problems with the standard primary energy factor currently used for electricity, which is 2.5 and used, among others, in the Energy Efficiency Directive.

The first problem is the lack of unequivocal scientific values, that is, the introduced value of 2.5 already dates the years of 2001 and 2003 when they were mentioned by different authors, from which can be concluded that such value is outdated according to the emission factors and the different energy productions available in the current year.

The second error is the lack of consistency, and it can be explained because the EU directives give the option to the states to assign a PEF value, thus avoiding the base value of 2.5, as can be seen in Energy Efficiency Directive (EED) (2012/27 / EU) Annex IV in the conversion tables. Moreover, these guidelines even advise to use values that are slightly different from the standard.

Lastly, the problem of lack of transparency is due to the fact that PEF values do not appear to be based on clear algorithms or scientific arguments, Surmeli-Anac et al. (2014) adds that it is likely that the values used as the supply of electricity will change over the years and cause PEF to change.

3. PRIMARY ENERGY FACTOR (PEF) CALCULATION METHODS

Primary energy is an energy form found in nature that has not been subjected to any human engineered conversion or transformation process. It is energy contained in raw fuels, and other forms of energy (non-renewable or renewable) received as input to a system. Several definitions of primary energy can be found, but it can be concluded that, basically, fossil fuels, such as natural gas, coal, oil, and lignite taken from a stock of finite resources are indeed primary energy.

The conversion efficiencies for steam power plants, heat plants, combined heat and power (CHP), or residential heating systems using combustible energy are determined based on the ratio between the produced electricity and/or heat, and the energy input (fuel quantity multiplied with the calorific value) as described in Equation (3.1). In the context of renewable energy carriers, the equivalent expression of primary energy is used instead of efficiency.

$$PEF=\frac{CF_f \times Input_{f,t}}{Output_t} \tag{3.1}$$

where CF_f is the calorific value of a fuel, $Input_{f,\,t}$ is the input of fuel per operation time and Output is the output of electricity and/or heat per operation time

As a consequence, primary energy factors are given by the quotient of primary energy input to energy (electricity/heat) output, i.e. the reciprocal value of the conversion efficiency as shown in Equation (3.2).

$$Efficiency=\frac{Output_t}{CF_f \times Input_{f,t}} \tag{3.2}$$

Looking to non-combustible energy sources, there are options to account primary energy for electricity and heat generation, as presented in Table 3.1. There are a few methods to take primary energy into account in renewable energy sources, as well as in nuclear energy. In these methods, the primary energy for the production of electricity is calculated by the calorific value of the fuel, as well as the amount of the same to generate a unit of electricity or heat.

Table 3.1- Options to account primary energy for electricity and heat generation from non-combustible energy sources. Adapted from Stoffregen, A. and Schuller, O. (2015).

No.	Option	Type of primary energy
1	The primary energy factor for electricity or heat from non-combustible renewables (hydro, wind, solar, geothermal) is accounted as zero by definition, e.g. 0 $MJ_{primary\ energy}$ per 1 $MJ_{electricity}$	Not applicable.
2	Primary energy equivalents are used to calculate the primary energy of noncombustible energies (renewable energies excl. biomass) and the special case of nuclear energy.	Accounting for (total) primary energy.
3	The primary energy factor for electricity or heat from renewables only accounts the fossil primary energy that was necessary to produce construction materials for the infrastructure (e.g. hydropower reservoir, wind turbines, photovoltaic cells, solar thermal power plants, and geothermal power plants) including fuels for transport and auxiliary materials during operation. For electricity from nuclear energy, the consumed fuel is also accounted as nonrenewable primary energy using a technical conversion efficiency or a primary energy equivalent.	Split up into non-renewable (fossil) and renewable primary energy. Accounting for non-renewable (fossil) primary energy only.
4	The primary energy factor is split up into fossil primary energy (e.g. infrastructure, conversion of nuclear energy) and renewable primary energy using primary energy equivalents or efficiencies for the conversion of renewable energy sources into electricity or heat.	Split up into non-renewable (fossil) and renewable primary energy. Accounting for non-renewable (fossil) and renewable primary energy.

With these options, it is necessary to analyze the methods that can be used to calculate the PEF, such as:

i) <u>Zero equivalent method</u>

It is not much practiced, but it can be considered that primary energy, for the production of electricity or heat through renewable sources, is null. The "Zero equivalent method” accounts no primary energy at all (Esser and Sensfuss 2016). This happens when energy is recovered through waste. For example, 1MJ of electricity from solar energy equals 0 MJ of primary energy. Consequently, the name of this method appears in several articles because the value of the primary energy is zero (Stoffregen and Schuller 2014).

ii) Direct equivalent method

This method uses a primary energy equivalent of 100% for electricity or heat for all non-combustible renewable energy sources, such as solar, wind or hydropower, and nuclear energy, i.e. one MJ of electricity from photovoltaic energy equals to 1MJ of primary energy from solar energy. It is considered the same for heat. This method is not used for renewable energy sources such as or biomass because it is possible to evaluate the primary energy needed to generate a unit of electricity or heat by measuring the input mass and calorific value of the same fuels with renewable energy sources (Stoffregen and Schuller 2014). It highlights the positive effect of non-combustible renewable energy sources (RES) fuels on climate change (Esser and Sensfuss 2016).

iii) Physical energy content method

By some definitions, primary energy must be the first energy in the generation process for which there are varied uses. Looking at the example of biomass the primary energy to produce electricity can be directly obtained by measuring the mass and their calorific value. For renewable energy sources like the wind and water, its practical and primary utility is electricity generation.

Then, there are energy sources that first must be transformed into heat, which is defined as the first usable energy, and so the heat energy needed to produce a unit of electricity is seen as the primary energy (e.g. nuclear, solar thermal, thermal geo). The efficiency conversions used in the transformation of heat into electricity usually varies in different energy statistics using this method. An example is the assessment of geothermal energy that separates heat as primary energy taken from the environment (soil) and still as secondary energy that is used for other purposes. This difference is determined by the efficiency conversion or the primary energy equivalent in the same way for electricity (Stoffregen and Schuller 2014). Studies further add that the conversion is five times greater than in the conversion of electricity. For electricity from non-combustible RES, the PEF value is 1 (Esser and Sensfuss 2016).

iv) Substitution method

The U.S. Energy Information Administration defines primary energy in the substitution method as "energy in the form that is accounted for the first time in a statistical energy balance, before any transformation to secondary or tertiary forms of energy". Unlike the primary energy definition of the method presented above, by this definition, it is necessary to determine the kinetic energy required by MJ of electricity from a wind turbine. Since it is difficult to determine the technical efficiency of converting non-combustible renewable energy sources, the conversion efficiencies of fossil fuel plants that have been replaced by renewable energy are used in the substitution method. To produce heat, as well as the generation of electricity, the conversion efficiency of the fossil fuel heat power plant that has been replaced by the heat of renewable energies are used. In the production of heat and electricity mix, the individual conversion efficiencies substituted are used in the same way (Stoffregen and Schuller 2014).

v) Technical conversion efficiencies method

This latter technical conversion efficiency provides an additional way to obtain the primary energy from the generation of electricity from non-combustible energy sources. There is a standard called VDI 4600 that is used in this method to calculate the technical efficiencies for the generation of electricity. In this standard, the primary energy is defined as the "energy content of energy carriers that have not yet undergone any conversion". However, there is a consequence, the cumulative energy demand method uses the technical conversion efficiency between the energy source and the generated electricity/heat, to calculate the primary energy demand per unit of energy generated. Table 3.2 presents the calculation for this technical conversion efficiency for the production of electric power (Stoffregen and Schuller 2014). In summary, this method says that the PEF of the fuel is 1 and in order to determine the PE demand to generate one kWh of electricity it uses the conversion efficiencies of the technologies.

Table 3.2- Calculation of technical conversion efficiencies for electricity generation in VDI 4600.

Energy source	Calculation of conversion efficiency
Hydro	Ratio of net electricity generated to the potential energy of water defined by height of fall and amount of water used per time period.
Wind	Ratio of net electricity generated to kinetic energy that passes the rotor area per time period.
Solar photovoltaic	Ratio of net electricity generated to the solar energy radiated on the gross area of the photovoltaic modules per time period.
Waste	Net calorific value of waste and amount of fuel used to calculate conversion efficiency (analogous to fossil fuels).
Biomass	Net calorific value of biomass and amount of fuel used to calculate conversion efficiency (analogous to fossil fuels).
Nuclear	33% used as default value (German average).

The calculation of these efficiencies for non-fuel energy sources depends on the climatic conditions, the used technologies and still on several "assumptions". In the case of wind energy, it must be taken into account the efficiencies of the mechanical parts of the wind turbine, such as the rotor, the gear, and the generator, and it depends on the surrounding environmental conditions and the technologies used.

The primary energy factors for electricity or heat from a generation using these technical efficiency conversions can be mathematically calculated in some ways. The easiest is to use the proportionality used by the IEA, and in this way, the conversion efficiency is assumed for both the same heat and the electricity, and then one obtains overstated efficiency for the electricity production and an understated efficiency for the heat production. Consequently, the pre-set efficiency of the heat tries to overstep this effect using the fixed efficiency for the generation of heat in a CHP power plant, for example, 90%. (IEA 2013B). If the primary energy required for heat is subtracted, using the fixed efficiency, from the general input of primary energy, the efficiency can be calculated for the generation of electricity (Stoffregen and Schuller 2014).

A summary of the methods introduced for different options (Table 3.1) is shown in Table 3.3

Table 3. 3- Methods used to determine the primary energy factors for electricity generation from different energy sources.

			Option 1	Option 2	Option 3	Option 4
Type of primary energy			(Total) primary energy	(Total) primary energy	Non- renewable primary energy	Non-renewable and renewable primary energy
System boundary			Energy conversion only	Energy conversion only	Entire supply	Entire supply
Non-renewable and renewable primary energy	Nonrenewable	Combustibles (e.g. coal, oil)	n.a.	• Technical conversion efficiencies	Supply of fuels/infrastructure based on life cycle approach. For conversion: • technical conversion efficiencies	
		Non-combustible (e.g. nuclear)		Primary energy equivalents: • direct equivalent method • physical energy content method	Supply of fuels/infrastructure based on life cycle approach. For conversion: • technical conversion efficiencies • physical energy content method	
	Renewable	Combustibles (e.g. biomass, waste)	Zero equivalent method	Technical conversion efficiencies	Supply of fuels/ infrastructure based on life cycle approach.	Supply of fuels/ infrastructure based on life cycle approach. For conversion: • technical conversion efficiencies
		Non-combustible (e.g. hydro, wind, solar, geothermal)		Primary energy equivalents: • direct equivalent method • physical energy content method • substitution method		Supply of fuels/ infrastructure based on life cycle approach. For conversion: • technical conversion efficiencies • physical energy content method

Applying the methods in practice in different sources of renewable energy is verifiable the conversion efficiency, and the Table 3.4 is a study of the life cycle assessments (LCA), used internationally and mainly in the European Commission to access the environmental impacts of products, processes, and services over the life cycles. Table 3.4 refers to the gross production and electricity produced directly without considering combinations of heat and power.

Table 3.4 - Primary energy equivalents and conversion efficiencies for electricity generation (gross production) of renewable energy sources.

Energy Source	Method i)	Method ii)	Method iii) [d]	Method iv) [d]	Method v) [e]
Hydro	n.a.	100%	100%	39.7% [c]	85%
Wind	n.a.	100%	100%	39.7% [c]	40%
Solar (photovoltaic)	n.a.	100%	100%	39.7% [c]	13.4%
Solar (thermal electric)	n.a.	100%	33%	39.7% [c]	12.4%
Geothermal	n.a.	100%	10%	39.7% [c]	22.4%
Biomass (solid)	n.a.	28.6% [a]	28.6% [a]	28.6% [a]	28.6% [a]
Biogas & Bioliquids	n.a.	26.2% [a]	26.2% [a]	26.2% [a]	26.2% [a]
Waste	n.a.	17.7% [b]	17.7% [b]	17.7% [b]	17.7% [b]
Nuclear	n.a.	100%	33%	33%	33%
Imported electricity	n.a.	100%	100%	100%	source specific. i.e. country specific

[an] average European gross efficiency for biomass powered electricity plants (IEA 2012B), reference year 2010

[b] average European gross efficiency for municipal solid waste incinerators, producing electricity only (CEWEP 2012)

[c] substituton via average European fossil power plant for non-combustible renewable energy sources (gross efficiency), calculated by PE International based on IEA (2012B), reference year 2010

[d] As applied by Eurostat and IEA

[e] As applied in LCA databases, e.g. (GaBi 2012)

Table 3.5 presents the results of the calculation of these factors for renewable energy sources using these different methodologies. The data are reported for gross production (without transmission and distribution losses). Primary energy factors are calculated through primary energy equivalents in option 2, but there may be a misinterpretation if electricity supplies are compared across multiple energy sources. One example is the electricity generated through biomass (and others from the heat) since it has primary energy factors much higher than those associated with electricity from wind, hydro or photovoltaic generation. However, no differentiation is made between renewable and non-renewable primary energy, because under normal conditions biomass would have a higher primary energy factor than electricity from fossil fuels due to the lower conversion efficiency. For option 3 and 5, the value for the non-renewable primary energy factor is taken from a database annually updated by the PE

International, as well as the option 4 that is based on the primary energy equivalents for the physical content method or the technical conversion efficiencies (GaBi (2012**)**.

To get a sense of the average primary energy factors at country level, Table 3.6 presents the specifications for three countries:

- Norway, which has a large percentage of renewable energy in the generation of electrical energy (95.9% in 2010 (IEA 2012B)).
- Poland that has an electricity generation based on fossil fuels (92.7% in 2010 (IEA 2012B))**.**
- Spain that applies a mix of the two and has the following characteristics: 20.5% nuclear power, 33.2% renewables, 46.3% fuel fossil fuels (IEA 2012B).

Table 3.5- Primary energy factors for renewable sources, nuclear and waste electricity following different accounting options (described in Table 3.1) and the methods previously mentioned.

	Option 1	Option 2			Option 3	**Option 4**			
$MJ_{primary\ energy}$ / $MJ_{electricity}$	i)	2a – ii)	2b - iii)	2c – iv)	Only NR - PE	4a- v)		4b – iii)	
	(Total) PE	(Total) PE			NR - PE	NR - PE	R - PE	NR - PE	R-PE
System boundary	Energy conversion only	Energy conversion only			Entire supply chain	Entire supply chain			
Hydro (SPS)	0	1.0	1.0	0.0035[e]	1.2	0.0035[e]	1.0	0.0035[e]	1.0
Hydro (RRPS)	0	1.0	1.0	0.010[e]	1.2	0.010[e]	1.0	0.010[e]	1.0
Wind	0	1.0	1.0	0.032[e]	2.5	0.032[e]	1.0	0.032[e]	1.0
Solar (PV)	0	1.0	1.0	0.15[e]	7.5	0.15[e]	1.0	0.15[e]	1.0
Solar (TE)	0	1.0		0.11[f]	8.1	0.11[f]	3.0 [a]	0.11[f]	3.0[a]
Geothermal	0	1.0		0.0048[e]	4.5	0.0048[e]	10.00	0.0048[e]	10
Biomass (SB-PP)	0	3.5[b]			0.18[e]	0.18[e]	4.0[b]	0.18[e]	4.0[a]
Biomass (B-GT)	0	3.8[b, c]			0.18[e]	0.18[e]	11[b, c]	0.18[e]	11[b, c]
Waste	n.a.	5.6[d]			3.2[d, e]	3.2[d, e]	2.9[d]	3.2[d, e]	2.9[d]
Nuclear	n.a.	1.0	3.0[a]	3.1[e]	0.0	3.1[e]	0.0		

[a] default primary energy equivalents from IEA (2012A) used for physical energy content method; [b] average European efficiency for biomass or biogas powered electricity plants (IEA 2012B), reference year 2010; [c] in Option 2 the net calorific value of the biogas is used, in Option 4 the net calorific value of the biomass used to produce biogas is used [d] average European efficiency for municipal solid waste incinerators producing electricity only (CEWEP 2012), 50% of fuel (waste) accounted as renewable and 50% as non-renewable primary energy; [e] Primary energy factors for fuel supply and infrastructure taken from the professional Life Cycle Assessment (LCA) database, developed and annually updated by PE International (GaBi (2012)); [f] Heath 2011.

Table 3. 6- Primary energy factors for renewable sources, nuclear and waste electricity determined for Norway, Poland and Spain

	Option 1	Option 2			Option 3	Option 4			
$MJ_{primary\ energy}$ /	i)	2a – ii)	2b - iii)	2c – iv)	Only NR - PE	4a- v)		4b – iii)	
$MJ_{electricity}$	(Total) PE	(Total) PE			NR-PE	NR. PE	R-PE	NR-PE	R-PE
System boundary	Energy conversion only	Energy conversion only			Entire supply chain	Entire supply chain			
Imported electricity – Hydro	0	1.0			0.0035[a, b]	0.0035[a, b]	1.2[b]	0.0035[a, b]	1.0[b]
Grid mix Norway	n.a.	1.2	1.2	0.086[b]	0.086[b]	0.086[b]	1.25	0.010[e]	1.1
Imported grid mix electricity --Norway	n.a.	1.0			0.086[a, b]	0.086[a, b]	1.25[b]	0.086[a, b]	1.1[b]
Grid mix Poland	n.a.	2.9	2.9	3.0 [a]	3.0 [a]	3.0 [a]	0.21	0.15[e]	0.19
Imported grid mix electricity -Poland	n.a.	1.0			3.0[a, b]	3.0[a, b]	0.21[b]	3.0[a, b]	0.19[b]
Grid mix Spain	n.a.	1.7	2.1	2.0[a]	2.0[a]	2.0[a]	0.83	0.0048[e]	0.35
Imported grid mix electricity -Spain	n.a.	1.0			2.0[a, b]	2.0[a, b]	0.83[b]	2.0[a, b]	0.35[b]

[1] Primary energy factors for fuel suppy and infrastructure taken from the professional Life Cycle Assessment (LCA) database, developed and annually updated by PE International (GaBi (2012)), [2] It is assumed for demonstration propose that the transmission losses of a grid mix are equal with transmission losses of an imported grid mix

4. PORTUGUESE CASE STUDY

4.1. ENERGY PRODUCTION AND CONSUMPTION

To analyze the evolution of the production of electric energy it is necessary to access the values provided by the Direção Geral de Energia e Geologia (DGEG). Table 4.1 shows the production of electric energy from different renewable energy in Portugal by year, so it is easier to conclude about the evolution of renewable energy in this country.

Table 4.1- Portugal’s electric energy production (GWh) from 2009 - 2018 (adapted from DGEG, 2018).

	Annual Production (GWh)									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018 feb
Total Renewable (1)	19016	28754	24692	20411	30610	32453	25514	33448	24108	23527
Hydric	9009	16547	12114	6660	14868	16412	9800	16909	7492	6882
Great Hydric	7648	1454	10615	5683	12931	14168	8669	14909	6568	6012
in pumping	724	399	578	1038	1138	843	1139	1186	1735	1792
PCH (>10 and <=30MW)	600	972	620	367	739	866	379	780	345	321
PCH (<=10MW)	761	1121	879	611	1198	1377	752	1221	579	549
Wind	7577	9182	9162	10260	12015	12111	11608	12474	12253	12292
Biomass (2)	1713	2226	2467	2496	2516	2578	2518	2481	2571	2557
With cogeneration	1364	1560	1722	1710	1780	1813	1723	1721	1775	1762
Without cogeneration	349	665	745	786	736	765	795	760	796	795
Municipal solid waste (MSW)	579	577	592	490	571	481	584	610	640	632
Renewable fraction	290	289	296	245	286	240	292	305	320	316
Biogas	83	100	161	210	250	278	294	285	287	283
Geothermal	184	197	210	146	197	205	204	172	217	223
Photovoltaic	160	215	282	393	479	627	799	822	968	974
Normalized total(3)	20411	22905	25094	25438	26195	27580	28183	29205	29507	28237
Normalized Hydric	10978	11478	12187	11587	11333	11860	12074	12627	12396	11392
Normalized Eolic	7003	8401	9492	10361	11135	11791	12002	12513	12749	12493
Gross production + imported balance (4)	54260	56318	54700	53471	53311	52862	53551	54007	54916	54651
% renewables (real)	35.00	51.10	45.1	38.2	57.4	61.4	47.6	61.9	43.9	43.05
% renewables (directive)	37.60	40.6	45.8	47.6	49.1	52.2	52.6	54.1	53.7	51.67

(1) excludes non-renewable sources fraction of municipal solid waste; (2) Includes vegetable wastes. forestry and sulfite liquors; (3) Directive 2009/28/CE; (4) Gross production + import balance is estimated for 2017 and 2018. Excludes pumping

As seen above, the energy production by hydropower is the most unstable form of energy production over the years, it had low values in 2009 but then the production was higher on 2010, 2011, 2013 and 2016, nowadays the values are one of the lowest in years. In terms of wind, biomass, waste, biogas and photovoltaic energy production are clearly increasing over the years, for example, wind production went up by 62%, and photovoltaic increased by 500%. According to the Associação Portuguesa de Energias Renováveis (APREN), this increase in the production surpassed the consumption necessity by 10% at some point, in a specific month. This rise is due to the growth of the necessity of the population in addition to all the renewable energy production equipment being evolving over time, making them more efficient.

But it is necessary to have a deeper knowledge about the variation of these values over a year, and for this, it is necessary to observe the results obtained with the monthly registration of this energy production through renewable energies, in Portugal, as can be seen in Table 4.2.

Table 4.2- Monthly GWh from different renewable energy in Portugal (adapted from DGEG, 2018).

	Annual Production (GWh)											
	2017										2018	
	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	January	February
Total Renewable	2733	2047	1776	1654	1692	1665	1583	1439	1773	2387	2453	2324
Hydric	1063	672	588	463	388	425	362	321	435	634	715	817
Great Hydric	884	584	504	423	361	401	340	301	301	558	542	696
in pumping	188	233	155	118	84	86	90	126	126	240	148	153
PCH(>10 and <=30MW)	64	32	26	14	9	8	6	7	7	28	69	51
PCH(<=10MW)	115	56	57	26	19	16	15	12	12	47	104	70
Wind	1300	997	836	829	908	841	848	762	762	1401	1390	1177
Biomass	223	216	201	198	219	223	205	207	207	224	225	205
With cogeneration	160	151	132	129	148	153	142	142	142	158	152	142
Without cogeneration	63	65	69	68	71	70	63	66	66	65	72	63
Municipal solid waste (MSW)	57	58	29	50	59	58	58	53	53	61	58	49
Renewable fraction	29	29	14	25	30	29	29	27	27	31	29	25
Biogas	27	25	25	24	23	24	23	23	23	23	24	21
Geothermal	18	17	18	16	17	18	20	21	21	20	20	19
Photovoltaic	75	91	94	99	106	104	97	79	79	55	50	60

In this point of view, it is easier to observe the variation of this production throughout the different seasons of the year, if the division is made by months considering winter (December, January and February), Spring (March, April, May), Summer (June, July and August) and Autumn (September, October and November). Then, looking first at hydropower, it is observable high values in the winter and a constant descent after this, until arriving again to the colder and rainy months, and in this case, a correlation between these two factors was found. In wind power, there is a similar variation with a rise of the values in the month of November. In contrast, the photovoltaic energy generation is higher in the summer months. There are no relevant variations on the part of biomass and biogas in the different seasons of the year.

After analyzing the variation over the months, it is also important to see how these values vary over the past few years in terms of installed power. Table 4.3 corresponds to the power installed in Portugal from 2009 to February 2018.

Table 4.3- Installed power (MW) from different renewable energy in Portugal (adapted from DGEG, 2018).

	Annual Production (GWh)									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018 feb
Total Renewable	9104	9682	10624	11310	11310	11677	12292	13389	13773	13787
Hydric	4883	4896	5330	5533	5533	5570	6053	6838	7099	7109
Great Hydric	4234	4234	4666	4877	4877	4916	5389	6169	6430	6430
PCH(>10 and <=30MW)	279	279	279	257	257	254	255	254	254	264
PCH(<=10MW)	369	383	385	399	399	400	409	414	414	414
Wind	3564	3914	4378	4731	4731	4953	5034	5313	5313	5313
Biomass	408	592	575	564	564	539	552	564	580	580
With cogeneration	323	476	459	441	441	416	428	434	434	434
Without cogeneration	85	116	116	123	123	123	123	130	145	145
Municipal solid waste (MSW)	86	86	86	86	86	86	89	89	89	89
Biogas	24	31	51	68	68	81	85	89	90	90
Geothermal	29	29	29	29	29	29	29	29	33	33
Photovoltaic	110	134	175	299	244	419	451	467	569	573
Photovoltaic of concentration	0	0	0	0	0	6	9	9	14	14

At the general level, more properly in hydric, wind and photovoltaic energy, a significant rise in installed power through the various renewable energies is observable, which indicates that the country is focused on the development of these sources for the production and installation of power.

-Hydric energy increased by 46%

-Wind energy increased by 49%

-Photovoltaic energy increased by 420%

This increase that has happened in Portugal can also be seen in Table 4.4, which presents the data on the production of electricity in countries of the European Union. This table shows the values of total production as well as the percentage represented by renewable energy sources in 2005 and 2016 and includes a final balance.

According to this data, it is possible to conclude that there are several countries that have decreased the total production of electric energy, but all have increased production through renewable energy sources. This factor is interesting since there is the concern of the countries in the investment in this type of production even if the total production decreases. Specifically, in Portugal, total production increased and there was a significant increase in production through renewables sources, confirming previous data. It is important to note that in this list, Portugal is the third country in the EU (at the percentage level) that uses renewable energy sources the most, with 55.5% of total production coming from them, equivalent to 33.4 TWh produced in 2016.

Table 4.4- Electricity production in EU countries in 2005 and 2016 (adapted from DGEG, 2018).

Electricity production in EU countries								
	2005			2016			Δ% 16/05	
	Total	RES	%RES	Total	RES	%RES	Total	RES
Austria	63.1	39.9	63.3	75.6	50.7	67.1	19.8	27
Sweden	159	80.9	50.9	143.1	87.7	61.3	-10	8
Portugal	53.9	15.3	28.5	60.3	33.4	55.5	11.8	118
Denmark	36.8	9.5	25.8	35.2	18.2	51.9	-4.5	92
Italy	293.6	44.1	15	245.2	108.2	44.1	-16.5	145
Spain	291.5	49.4	17	257.6	104.6	40.6	-11.6	112
Greece	59.2	5.9	10	39	14.9	38.1	-34.1	150
Finland	70.5	22.9	32.5	87.6	30.5	34.9	24.2	33
Germany	612.1	61.8	10.1	625.5	188.2	30	2.5	204
Ireland	25.7	1.9	7.3	30.1	7.3	24.4	17.1	292
UK	396.6	15	3.8	322.9	73.8	22.8	-18.6	392
France	570.6	56.7	9.9	514.1	95.3	18.5	-9.9	68
Belgium	93.3	2.1	2.3	89.9	13.5	15.1	-4.3	541
Netherlands	100.2	7.5	7.5	119.8	14.9	12.4	19.6	98

RES-Renewable Energy Sources

The increase in energy production through these renewable energy sources is relevant for several sectors in Portugal and Table 4.5 presents the contribution of these sources to electricity, transport and heating/cooling in gross final consumption. Such consumption has been decreasing since 2008, but the contribution of renewable sources has increased, registering a percentage of 28.5% in 2016.The EU Directive 2009/28/EC sets the target for the incorporation of RES in gross final consumption of energy by 2020, which is 31% for Portugal.

Table 4.5-Renewable energy contribution to gross energy consumption (ktep) (adapted from DGEG, 2018).

RES contribution to gross final energy consumption (ktep) [(1)]									
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Gross Final Energy Consumption (GFEC)	18877	18645	18583	17768	16627	16334	16212	16401	16359
RES contribution	4332	4554	4492	4371	4098	4198	4377	4590	4663
Electricity	1598	1742	1955	2144	2174	2238	2355	2410	2494
Heating and Cooling	2600	2595	2218	2210	1905	1936	1858	1839	1892
Transports	134	218	319	17	18	25	164	341	277
RES's weight in GFEC	22.9	24.4	24.2	24.6	24.6	25.7	27	28	28.5

[(1)] Directive 2009/28/CE methodology

Other relevant data are the annual production of renewable energy, and this is presented in Table 4.6, where it is divided into different types of renewable energy to have a better perception of what is produced in Portugal. It is visible the use that the country makes through biomass with about 55% of the renewable energy coming from it.

Table 4.6- Annual renewable energy production in Portugal (adapted from DGEG, 2018).

	RES contribution to gross final energy consumption (ktep)								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Renewable	4242	4737	5373	4621	4621	5530	5727	5110	5089
Eletricity	1142	1456	2249	1501	1501	2369	2525	1927	1927
Biofuel	149	226	284	276	276	274	301	321	298
Biomass	2924	3019	2791	2775	2775	2812	2823	2781	2779
Wood and vegetal/forest waste	1986	2035	1550	1296	1296	1178	1240	1226	1188
Sulphite liqueurs	789	825	878	921	921	986	959	984	1042
Pellets and Briquettes	nd	nd	221	312	312	453	420	370	338
Biogas	23	25	32	56	56	65	82	83	80
Other Biomass (1)	1236	134	110	190	190	130	122	119	131
Other Renewables (2)	26	36	49	69	69	74	78	82	85

(1) Includes Renewable MSW fraction

(2) Includes solar thermal and low enthalpy geothermal

In Portugal nowadays, electricity is produced using different technologies and different primary energy sources (coal, natural gas, fuel, diesel, water, wind, sun, biomass, waste) and the number of producers has increased significantly, since in addition to the well-known thermal power plants and large hydroelectric power plants, many other ones of less power have appeared, in the scope of the cogeneration or the production of renewable origin. Redes Energéticas Nacionais (REN) operates the National Transmission Network (RNT) linking producers to consumption centers, ensuring a balance between energy demand and supply, being the only electricity transmission entity in Portugal, within the scope of an agreement with the Portuguese Government. Table 4.7 was designed with the data provided by REN on its own website, which provides real-time information on energy production and consumption in Portugal.

In May of 2018, a mirror of what was this year was obtained, since in a spring month the greatest source of renewable energy was thermal and wind, with the photovoltaic energy being low, given the bad weather. These values are useful because they confirm the previously stated that, in the spring months, the energy coming from the wind is high and the photovoltaic energy begins to increase since summer is approaching at the same time that the hydric one descends when moving away from the periods of more rain. But obviously, at any time of the year, only with almost no production from wind could the photovoltaic exceed it, because the photovoltaic power is much smaller than the wind.

Table 4.7- Demand, on 31/05/2018, 31/05/2017, May's total, and variation vs previous year's 2. month period, REN (2018).

	Peak (MW)	Day/2018 (GWh)	Day/2017 (GWh)	Month/2018 (GWh)	Variation (%)
Hydro	1952	17.2	13.8	995.7	95.5
Thermal	3099	64.5	98.8	1,524.20	-34.2
Ordinary Status Generation	4747	81.6	112.6	2,519.90	-10.8
Imports (Programmed)	805	3.4	0.9	354.6	45.2
Exports (Programmed)	1338	7.9	25.6	281.6	-32.8
Import Balance	-1353	-4.7	-24.7	71.3	-141.2
Pumping	230	0.6	1.5	96.9	-51.3
Hydro	140	2.3	0.7	91.3	46.8
Thermal	790	18.1	16.1	609.7	6.6
Wind	1083	15.5	16.7	717.8	-12.1
Photovoltaic	270	2.4	3.1	80.4	-4.8
Wave	0	0	0	0	0
Special Status Generation	2090	38.4	36.7	1499.10	-2.3
DEMAND	5550	114.8	123.1	3993.40	0.1
(Corr. Temperature)		114.9	121	3990.10	0.9

4.2. EVOLUTION OF AVERAGE EMISSIONS

The evolution of Greenhouse Gases (GHG) emissions largely reflects the evolution of the Portuguese economy, which was characterized by a strong growth associated with increased demand for energy and mobility in the 1990s, and the stagnation and recession in 2011, 2013, and has since sustained, as can be seen partially in Figure 4.1.

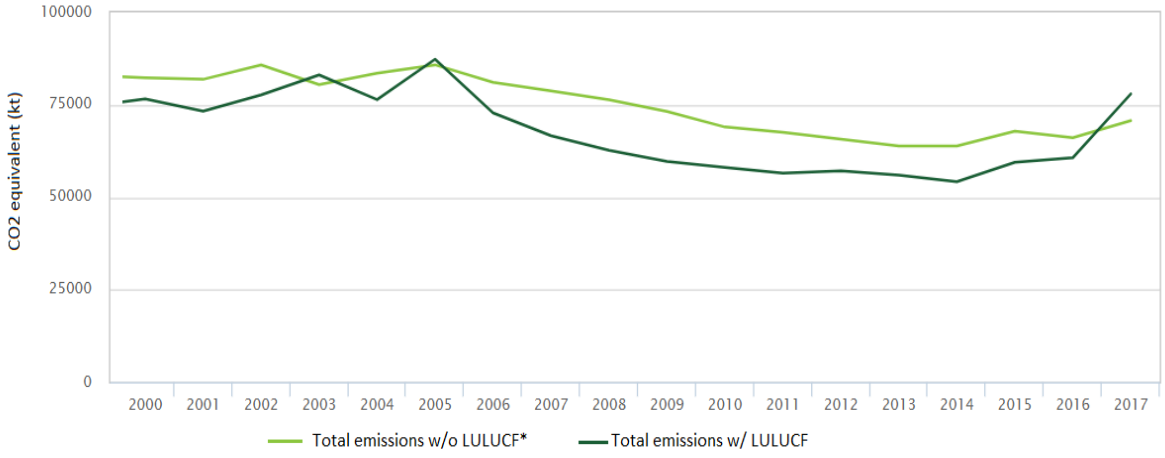

Figure 4. 1- Greenhouse Gases (GHG) emissions evolution (adapted from APA, 2019)

The emission stabilization / reduction trends started as a result of the technological improvements in pollution control and energy efficiency systems, the introduction of less polluting fuels, the growth in energy from renewable energy sources, the implementation of waste management measures, the reuse and recycling, and the increase and energy use of the quantities of biogas generated in waste management systems.

According to Agência Portuguesa do Ambiente (APA), GHG emissions, without accounting for Land Use, Land Use Change and Forestry (LULUCF) emissions, are estimated to be at around 70.7 Mt CO_2eq. for 2017, representing an increase of 19.5% over 1990 and a growth of 7.0% over 2016.

Considering the LULUCF sector, total emissions in 2017 are estimated at 78.0 Mt CO_2eq., Corresponding to an increase of 29.2% when compared to 1990 and an increase of 28.5% when compared to 2016. This sharp growth is related to the forest fires that occurred in the year 2017, a situation associated with a particularly dry year, the high temperatures that occurred outside the normal summer period, and unusually strong winds.

Emissions recorded in 2017 confirm a path towards meeting national and European emission reduction targets for 2020 and 2030. Total emissions, representing a reduction of about 18% over 2005 levels, are in the range of the PNAC target 2020.

To conclude the chapter, it is important to note that the production of energy through renewable source has a relevant role in Portugal. It is recorded in this country that is produced on average about 60 GWh and more than half is made with renewable (33.448 GWh in 2016), and wind and hydropower are the major contributors to this reality. Also, the share of renewables has increased and therefore the primary energy factor and emissions have decreased. These vary throughout the year and day, so both primary energy and emissions will vary and for the correct assessment one should take into account when energy consumption occurs.

5. MATERIALS AND METHODS

In order to analyze energy consumption and production through renewable sources, the load diagrams provided by REN - "National Energy Networks" provided by the supervisor from 2013 to February 2018 were acquired and this data gathers about 2.5 million discrete data. These diagrams contain the production and consumption every 15 minutes of each day of the years mentioned. Table A.1 from Appendix A gives an example of this data for a specific day of a year. These data were subsequently processed and statistically analyzed using the *JMP Pro software*.

The types of energy production that can be seen are fossil fuels such as coal, natural gas and fuel and non-fossil renewables such as reservoirs, water streams, hydraulic, thermal, wind, photovoltaic and waves. And, in addition, the energy of importation, exportation, and pumping. The main goal here is to separate fossil and renewable primary energies and focus only on the latter. Then the formulas will be applied to production types that use the sun, wind, rain, tides and geothermal energy as their primary energy source.

Since the data is divided into quarters of an hour, to have the energy production per hour, it is summed all this production in one day of each type of production and consume and finally divided by 4, as described in Equation (5.1) and (5.2), which is applied in all mentioned production types referred, thus obtaining the production in kWh (renewable is substituted by reservoirs, water streams, hydraulic, thermal, wind, photovoltaic and waves) . The data also have the consumption data, then it is possible to calculate the percentage of consumption in relation to renewable energy production, which is given by Equation (5.3).

$$\text{Daily Production}_{\text{renewable}}\text{(per hour)}= \sum \frac{\text{Production}_{\text{wind}}\text{(per quarter of an hour)}}{4} \tag{5.1}$$

$$\text{Daily Consume(per hour)}= \sum \frac{\text{Consume (per quarter of an hour)}}{4} \tag{5.2}$$

$$\text{Daily Consume}_{\text{renewable}}(\%)= \sum \frac{\text{Daily Production}_{\text{renewable}}\text{(per hour)}}{\text{Daily Consume (per hour)}} \tag{5.3}$$

5.1. VARIATION THROUGHOUT THE YEAR AND DEPENDING ON THE TIME OF DAY

With the results obtained was made two types of analysis, annual and daily. A comparison was made between the seasons of the year in relation to the use of renewable source and then days selected according to the average. Weather seasons always start on the first day of March, June, September, and December to simplify weather calculations and keep them uniform. So, it was defined that spring includes the months of March, April, and May; Summer contains the months of June, July, and August; Autumn includes the months of September, October and November; and finally, December, January and February are winter months. For the daily analysis, it is assumed that one has half a day at night and the other half with sun exposure, so it is assumed that from 19h until 07h will be the night and from 07h to 19h the day.

5.2. PEF AND EMISSION FACTOR CALCULATION METHODS

Primary energy (PE) sources are usually defined as inputs into the energy systems where it is converted into secondary energy (electricity, heat, or mechanical work), and can be determined by Equation (5.4). The primary energy factor (PEF) connects both primary and useful energy (UE), as described in Equation (5.5) (Noussan et al., 2018). The PEF is an indicator of how much primary energy is used to generate a unit of secondary energy, as shown in Equation (5.6). This parameter can also be determined through the individual PEF of each energy source, Equation (5.7) (Prek, 2019).

$$PE= \frac{EP}{\eta} \tag{5.4}$$

Where EP is the energy production and η is the primary energy conversion efficiencies described in chapter 4.

$$UE= PE\ (100-\text{Energy loss percentage}) \tag{5.5}$$

$$PEF= \frac{PE}{UE} \tag{5.6}$$

$$PEF= \sum_{\text{Energy type}} \frac{PE_{\text{energy source}}}{UE_{\text{energy source}}} \times \frac{EP_{\text{energy source}}}{EP_{\text{total}}} \tag{5.7}$$

The emission factor (EF) is the ratio between the amount of pollution generated and the amount of raw material processed or burned according to their specificity (EEA, 2019). Also, the EF can be determined using the life cycle CO_2 equivalent of each energy source and the specific energy production (EP).

$$EF_{CO2,\ energy\ source} = \text{Life cycle } CO_2 \text{ eq. } \times EP_{energy\ source} \tag{5.8}$$

In this work, for the determination of PEF and EF, the following data and methods were used:

- The EP values were obtained through the data collected from REN;
- The η used are those described in Method iii) summarized in Table 3.4;
- The UE was determined by assuming an average energy loss of 10% (Prek, 2019);
- The median Life cycle CO_2 eq. by energy source is described in Table 5.1.

Table 5. 1- Life cycle CO_2 eq. (gCO_2eq/kWh) values, Adapted from (Bruckner et al., 2014)

Technology	**Min.**	**Median**	**Max.**
Coal	740	820	910
Biomass – Cofiring with coal	620	740	890
Gas – combined cycle	410	490	650
Biomass – Dedicated	130	230	420
Solar PV – Utility-scale	18	48	180
Solar PV – rooftop	26	41	60
Geothermal	6.0	38	79
Concentrated solar power	8.8	27	63
Hydropower	1.0	24	22001
Wind Offshore	8.0	12	35
Nuclear	3.7	12	110
Wind Onshore	7.0	11	56

In this phase, the calculations were made using the Equations (5.1), (5.2) and (5.3), every day of the year, from January 2013 to February 2018, to be able to analyze in detail the production and consumption of energy through renewable energy. Thus, it is possible to obtain Figure 6.1 containing the monthly average of all the years of the referred period.

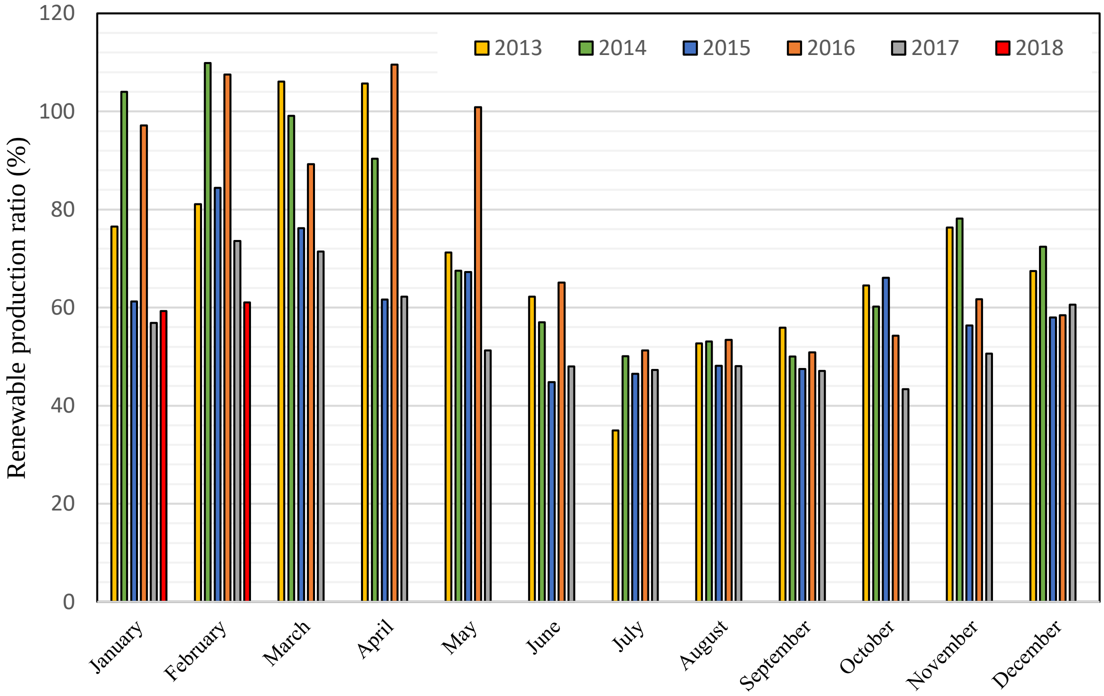

Figure 6. 1- Monthly renewable energy production and total energy consumption ratio between 2013 and 2018.

From this image, it is possible to make the desired analysis. In short, the data allow us to differentiate production over the years, and to verify that it really is quite different but keep the same trend over the years.

6.1. SEASONS

The monthly renewable production and total energy consumption ratio were then analyzed in terms of seasons for each year, Figure 6.2 a) and Figure 6.2 b). Note that the months in these figures are represented by numbers in order from January to December, represented by the numbers 1 and 12, respectively. Also, to note that both Figure 6.1 and 6.2 a) represent the same data but in different perspectives.

So, once obtained the data shown in Figure 6.2, there is a need to understand why spring and winter months present higher incorporation of renewable energies, for instance the use of renewable energy in July is in average about 51% of the renewable energy incorporated in March. For this, it is observed the production, individually, of each one of the studied energy sources. Obviously, there have to be "sample days" of each season, which are according to the average of the month and according to the production and consumption standards.

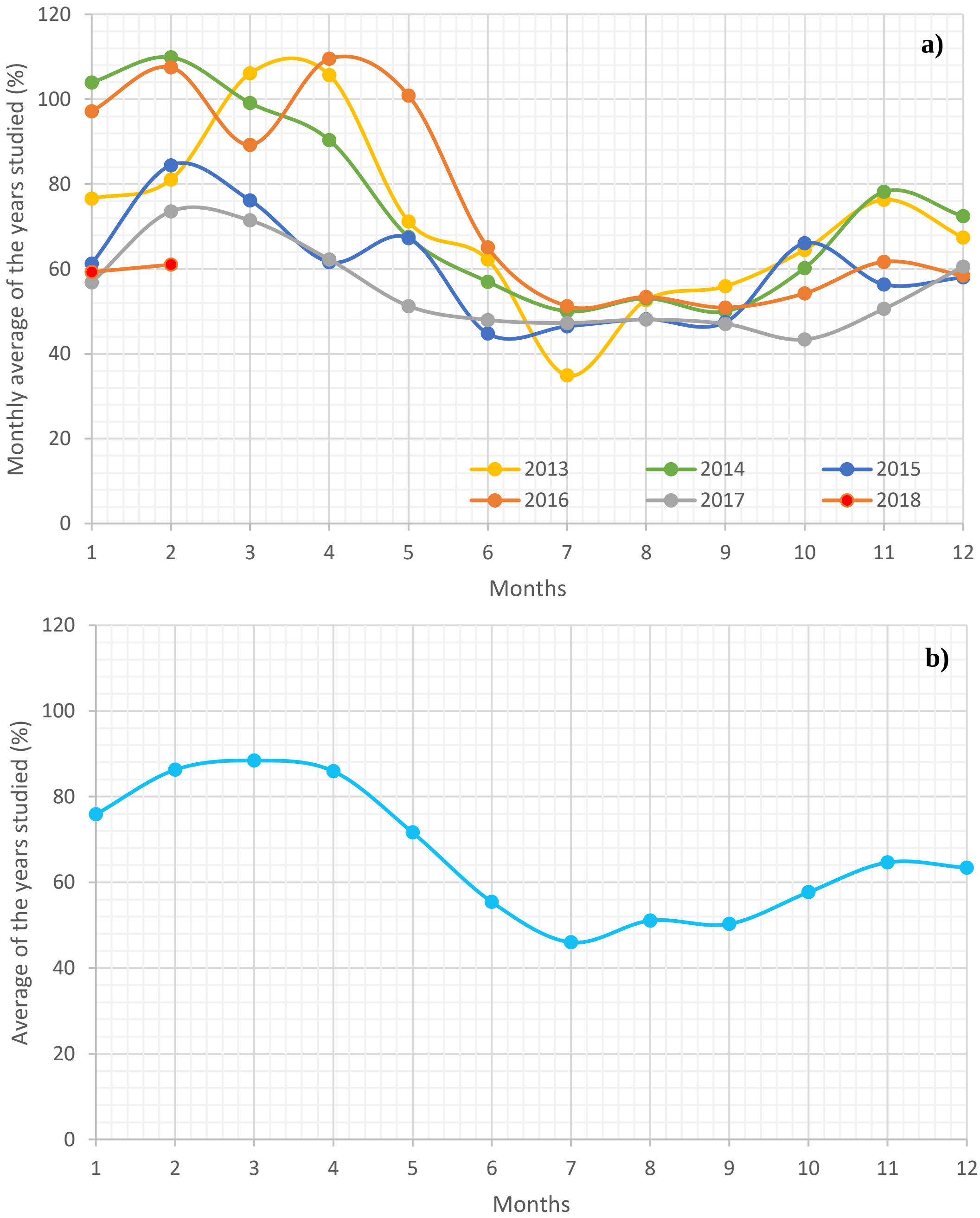

Figure 6.2- a) Monthly renewable production and total energy consumption ratio; b) Renewable production and total energy consumption ratio average from 2013-2018.

In Table 6.1 is shown the average energy production (in MWh) of one day in the spring, summer, autumn and winter period.

Table 6.1- Average energy production (in MWh) of one day in each season (2013-2018).

	Spring	Summer	Autumn	Winter
Reservoir	16393.85	4220.30	9058.75	44401.33
Water Threads	11324.48	3354.30	10654.78	49971.25
Hydraulic	3688.85	556.93	512.75	7782.95
Thermal	21416.98	20052.80	20407.38	20784.73
Wind	45578.08	24775.85	31726.28	40002.80
Photovoltaic	2720.10	3308.15	2584.20	386.58
Waves	0.00	0.00	0.00	0.00

Studying these data and with some theoretical knowledge it can be associated several factors, as for example, the hydraulicity in winter is much higher than in other seasons hence the energy production from the reservoirs, water threads, and hydraulics is higher, however, in this same season there is less production from the sun, but since the energy production through photovoltaic panels is not as much as the others in Portugal (as seen in Table 6.1) it can be confirmed that for calculation purposes it is normal that the production from water and wind has more visible effects. Therefore, such low values of renewable energy incorporation in summer are now understandable, since the largest source of energy in this season comes from the sun. The other sources of production aren’t able to compensate for this lower production in this season, resulting in a lower coefficient. The production through the wind turbines of all companies in Portugal is large, and it is also noticeable that the season has a higher impact, that is, it can be seen that in winter and spring the production through the wind is higher, which means that it is a factor that must be taken advantage of.

6.2. DAY AND NIGHT

It is also possible to study the production throughout the day, and see if there is any relationship between the energy and the time of the day.

6.2.1. Photovoltaic and Thermal

In the winter months, from 17:30h on average, there is no longer energy production from the photovoltaic panels and it is extended until 07h of the following day. However, as mentioned in the previous chapter, "day hours" are considered from 07h to 19h, so obviously it is needed to count some periods which the production is zero, which is perfectly natural. During those same hours on average, it has the same value as in total production, which in this case is about 386MWh. The same situation happens in autumn when the average at night is almost zero so all production through the sun during the day is the same as shown in Table 6.1. In the summer it is often said that the days are longer, in fact, what is meant is that there are more sunny periods than in other seasons, and this is seen in the data acquired and in the calculations made the result was a production of about 90MWh in a fraction of the period that was denominated as night in this process, and the remaining 3211.78MWh produced in the period denominated as day. Finally, in the spring, although there is energy production through the panels in the period referred to as night, which is around 15MWh (average), as usual, in the period from 07h to 19h the production is higher, around 2705MWh.

Among the different applications of solar thermal energy is the possibility of generating electric energy. The production in this type of source is very similar in different seasons over the days. In spring the production is about 53% during the day and at night the remaining 47% of the total production, in autumn and summer the values are very close to each other and 49% of the production is at night and 51% during the day in both cases. In winter the case is not much different, with an average production of 52% of total production in the daytime and 48% in the night.

6.2.2. Reservoir, water threads and hydraulic

These three sources of energy production have one thing in common, they all need water as a renewable source, mostly coming from rivers and indirectly dependent on the day's rainfall/hydraulicity. Having this dependency, it is predictable that the production percentages are very close, and this is what happens in all seasons. The percentages vary between day and night only around 10%, i.e. the production during the day is 55% and at night 45% on average or vice versa, for the case of the hydraulic energy. The reservoirs and water streams have a peculiar production since between midnight and 06h, this production is very small compared to the production in the other hours, which in many cases the production in the night is very low (because those hours are in this period), but on many other days the production in the other hours of the night can balance, and there it is, depends a lot on the precipitation and the hydraulicity of the day. That said assuming an average value would be misleading because in one day there may be a difference up to 50%, while as in other days the production was about the same.

6.2.3. Wind

Wind turbine generation, as can be seen, is one of the largest sources of energy in terms of production, although it varies in season, somewhat normal given the varied climate and geographical location of Portugal, there is no direct impact on whether it is day or night, the production on average is the same except when there are days with strong wind current.

6.3. PEF AND EMISSION FACTOR

6.3.1. Monthly variation of Primary Energy Factor and renewable share

Given the above production and applying the methods mentioned in the previous chapter it is possible to calculate and analyze the primary energy factor for the different months (and seasons) while comparing it with the contribution of renewable energy (in relation to total production). To carry out this analysis it was necessary to choose an "example year" so that it would be possible to study the variation over the months and through the day itself. It is possible to see, in Figure 6.3, the result of this test in relation to the variation over a year.

From Figure 6.3 what can be observed is that the contribution of renewable energy has a great impact on the value of PEF. In other words, the smaller the contribution, the greater the PEF value, and therefore it is assumed that the higher this value (PEF) is the greater the amount of "environmentally friendly" energy produced. It is also necessary to check whether these values change throughout the day, obviously, it is known that there is no photovoltaic production at night, but does it impact the PEF value? As it has been verified earlier that the seasons have an influence on the PEF calculation, it is fair to analyze four different months, one representative of each season. From these months a daily average of these values was made and studied for the 24 hours of the day. The months were chosen taking into account the average production values and the previously calculated values (at monthly level). Figure 6.4 shows this variation over the course of a day.

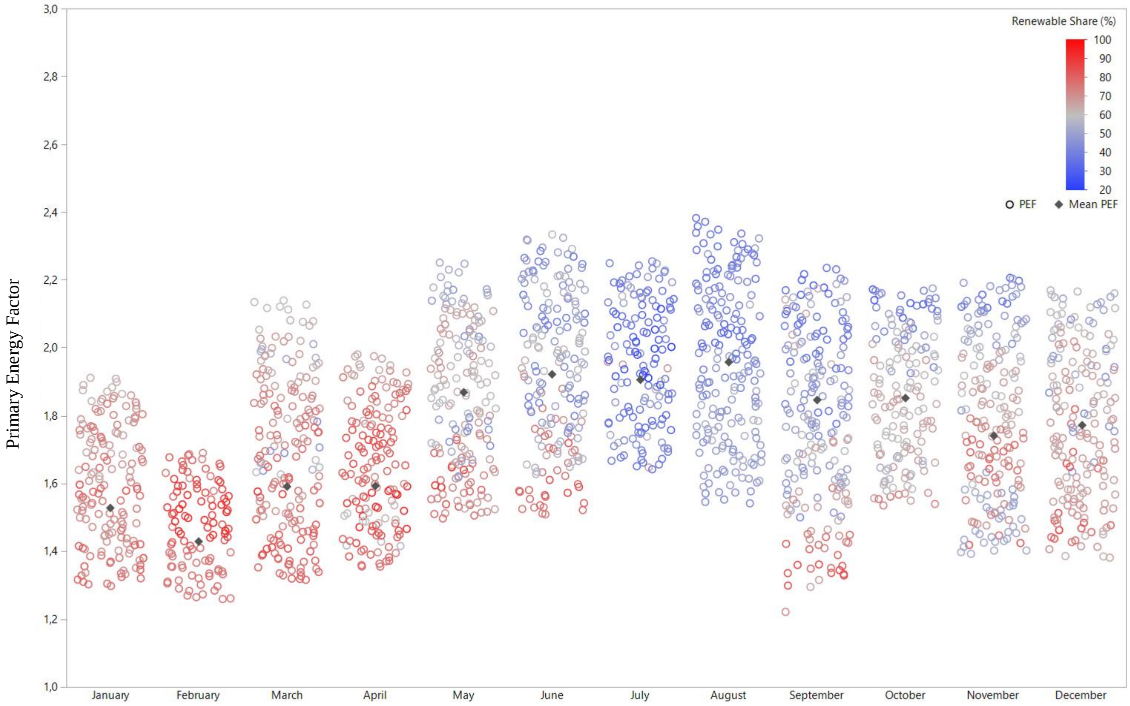

Figure 6.3- Monthly variation of PEF and renewable share from 2014.

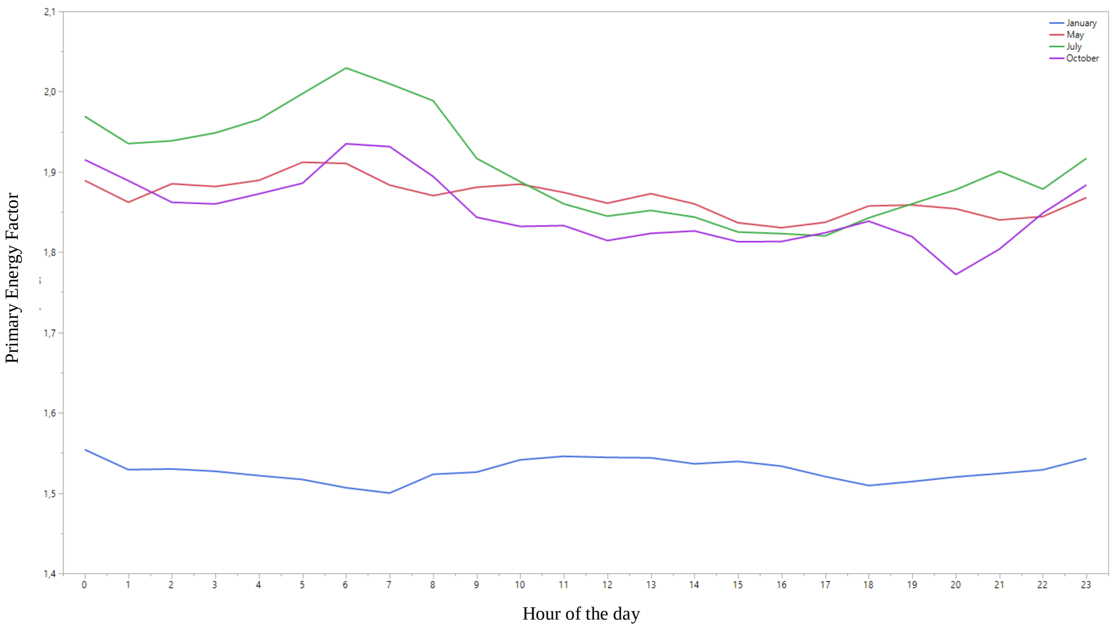

Figure 6.4- Hourly average variation of PEF and renewable share from 2014.

Using the equations and CO_2 emission values typical of each primary energy mentioned above and taking into account the contribution of each type of energy production in the total production, the total value of carbon dioxide equivalent emissions can be determined. Now, are CO_2 emissions (factor) related to the primary energy factor and the contribution of renewable energy? In Figure 6.5 this question can be answered.

All these observable points in this figure are the hourly outputs from all sources of the acquired data. The interesting thing about this figure, and answering the previous question, is that there is indeed a relationship between emissions and PEF. As seen earlier, PEF is related to the contribution of renewable energy. The larger this contribution, the smaller the PEF will be. So, of course, when there is a greater contribution from renewable sources, there will be a smaller contribution from non-renewables, which are the ones that release the most CO_2. This is observable in Figure 6.5. It is possible to say that a high PEF will have a higher CO_2 emission factor.

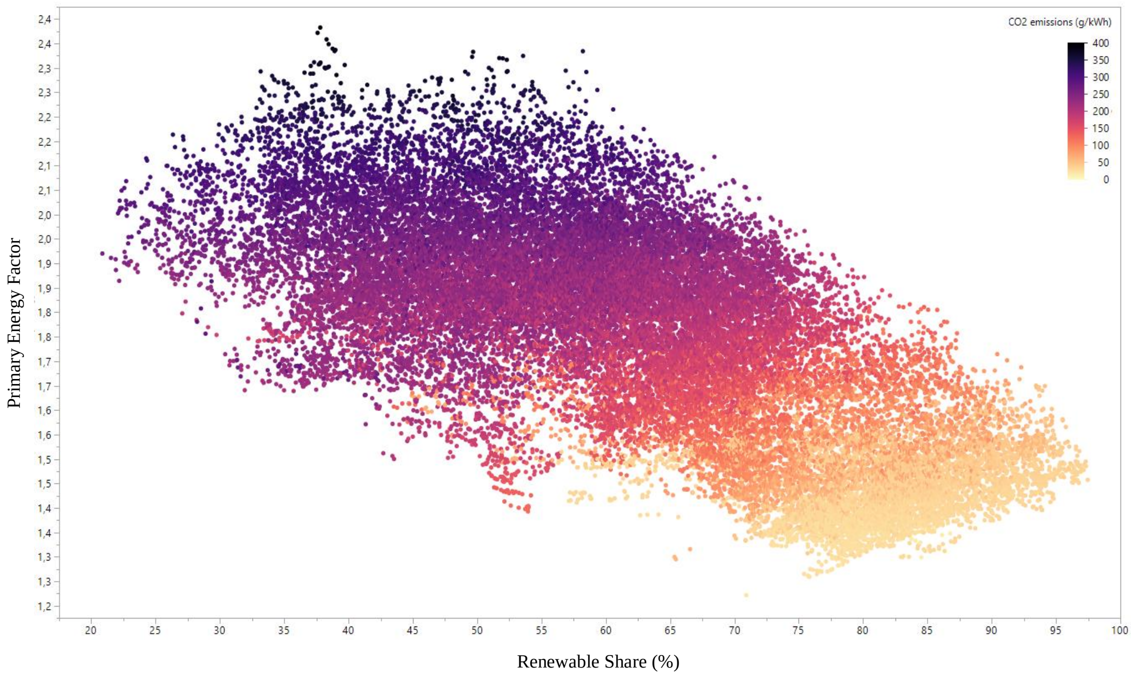

Figure 6.5. Relation between of primary energy factor, renewable share and CO_2 emission factor for 2014.

Finally, in order to be able to assign a updated PEF value to Portugal, an analysis of the last years was made, namely 2013, 2014, 2015 and 2017 to see if this value changes and if it is larger, smaller or even equal to that one. is assumed in the European Union, which in this case is around 2.5. The data are presented in more detail in Table 6.2.

Table 6.2- Portugal primary energy factor (2013, 2014, 2015 and 2017).

		2013					2014				
	Efficiency (%)	Generated GWh	PE GWh	PU GWh	PEF	Share (%)	Generated GWh	PE GWh	PU GWh	PEF	Share (%)
Coal	40	9935.9	24839.7	8942.3	2.8	18.8	11099.3	27748.2	9989.4	2.8	19.3
Fuel Oil	40	0.1	0.3	0.1	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas	40	1262.0	3155.1	1135.8	2.8	2.4	1467.9	3669.7	1321.1	2.8	2.6
Reservoirs	100	5965.8	5965.8	5369.2	1.1	11.3	6428.8	6428.8	5785.9	1.1	11.2
Water strands	100	6745.5	6745.5	6070.9	1.1	12.8	8267.6	8267.6	7440.9	1.1	14.4
Imports	100	4182.8	4182.8	3764.5	1.1	7.9	4073.8	4073.8	3666.4	1.1	7.1
Exports	100	2455.0	2455.0	2209.5	1.1	4.7	3171.4	3171.4	2854.3	1.1	5.5
Hydraulic	100	1311.9	1311.9	1180.7	1.1	2.5	1508.0	1508.0	1357.2	1.1	2.6
Thermal	33	7878.9	23875.6	7091.0	3.4	14.9	7949.0	24088.0	7154.1	3.4	13.8
Wind	100	11282.4	11282.4	10154.1	1.1	21.4	11813.0	11813.0	10631.7	1.1	20.6
Photovoltaic	100	394.5	394.5	355.1	1.1	0.7	588.3	588.3	529.4	1.1	1.0
Wave	100	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	1.1	0.0
Pumping	100	1356.6	1356.6	1220.9	1.1	2.6	1079.5	1079.5	971.5	1.1	1.9
Total PEF					1.80					1.79	

Table 6.3- (Continuation) Portugal primary energy factor (2013, 2014, 2015 and 2017).

		2015					2017				
	Efficiency (%)	Generated GWh	PE GWh	PU GWh	PEF	Share (%)	Generated GWh	PE GWh	PU GWh	PEF	Share (%)
Coal	40	430.9	1077.3	387.8	2.8	23.0	333.7	834.2	300.3	2.8	17.1
Fuel Oil	40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas	40	200.7	501.6	180.6	2.8	10.7	317.3	793.3	285.6	2.8	16.3
Reservoirs	100	89.0	89.0	80.1	1.1	4.8	110.2	110.2	99.2	1.1	5.6
Water strands	100	192.1	192.1	172.9	1.1	10.3	78.3	78.3	70.5	1.1	4.0
Imports	100	115.3	115.3	103.8	1.1	6.2	120.0	120.0	108.0	1.1	6.2
Exports	100	79.8	79.8	71.8	1.1	4.3	130.7	130.7	117.7	1.1	6.7
Hydraulic	100	27.3	27.3	24.6	1.1	1.5	19.9	19.9	17.9	1.1	1.0
Thermal	33	251.3	761.5	226.2	3.4	13.4	219.8	666.1	197.8	3.4	11.3
Wind	100	418.2	418.2	376.4	1.1	22.3	490.5	490.5	441.4	1.1	25.1
Photovoltaic	100	24.7	24.7	22.2	1.1	1.3	23.7	23.7	21.3	1.1	1.2
Wave	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pumping	100	43.4	43.4	39.1	1.1	2.3	107.2	107.2	96.5	1.1	5.5
Total PEF					1.98					1.92	

The analysis of Table 6.2 allowed the confirmation that the PEF value has changed over the course of the years and is different from the current standard value used (2.5). So, there is a necessity of constant actualization of this factor, in fact, this value, currently, should around 28% lower, so, the Portuguese actual PEF should be approximately 1.87 instead of 2.5.

7. Conclusion and future work

The production of electricity from renewable sources in Portugal has evolved as a result of the country trying to reduce the use of non-renewable sources. It was visible that energy production through renewable energy depended on the season and, apart from photovoltaics, did not depend much on the time of day. Production through wind towers as well as water sources has a great influence today, and the evolution of photovoltaic panels has been the most noticeable. But for calculation purposes, especially in summer, where photovoltaic production is higher, but wind and hydropower production are lower, this production cannot counteract other factors such as the contribution of non-renewable sources and their emissions.

The Primary Energy Factor, as mentioned, is outdated, and this has been proved in this work. The assumed value of 2.5 in the EU is much higher than the average calculated for Portugal, currently, this value should be used as 1.87, which is quite different from 2.5.

Using such a different PEF and assuming a fixed value misleads several emission calculations, which have been found to be related to the PEF value.

Since this value also varies over the seasons, the idea would be that the PEF value should be updated much more regularly, not daily but probably monthly, and obviously, it would be important to know this value and make it available on platforms.

It could not fail to be mentioned that, in the world lived in, and given the environmental and climate problems that the planet is going through, it is important to reduce energy production through non-renewable, polluting sources. It is possible to live in Portugal only dependent on energy production via "clean" sources, one is lucky to be a country rich in natural sources like the sea, the wind, and even the sun, obviously, it is necessary to invest a lot of money but this investment is necessary for human survival.

Future works on this subject may possibly contemplate the following topics:

As can be seen, the PEF value varies according to seasons, years, use of renewables and emissions. As there are data and studies of what production will look like in the coming years, so a work proposal would be to make predictions for future years, and if these forecasts do not have an acceptable PEF value, try to understand how the country could improve. With the work that has been done by the companies to achieve a Portugal more dependent on renewable energy for sure that in the near future there will be different values from those studied in this work. It is soon expected that several calculations used here will be outdated soon, so the monitoring of these factors, emissions, and energy production in Portugal must be continuous and it is possible to work on it.

In this thesis the focus is on mainland Portugal, and many data taken only take into account production and consumption in this, so a good idea would also be to study these cases for both Madeira Island and Porto Santo as well as for the Azores, as these, mainly the latter have different sources of energy production.

Another noticeable part is the fact that many data collected mention the energy production through waves and tides, however, we find the values at zero most times. It has already been mentioned that projects and future investments in this sector are a reality, so a good objective would be to calculate the same factors and the impact that these investments would have since Portugal is a country rich in aquatic resources.

In this dissertation, the focus is on electricity generation but RES are also used in the heating and cooling sector as well as in transport. So, it is very likely that PEF and Emission values will be different in this regard. It would be interesting to make a comparison with other countries that have different productions and standards.

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APPENDIX A

Table A. 1- Portugal demand diagram data for January 22 of 2017, provided by REN.

Data	Hora	Carvão	Fuel	Gás Natural	Albufeiras	Fios de Água	Importação	Exportação	PRE Hidráulico	PRE Térmico	PRE Eólica	PRE Fotovoltaico	PRE Ondas	Bombagem	Consumo
22/01/2017	00:00	1757.6	0	761.2	338.3	419.6	1123.6	0	13.9	772	659.3	0	0	0	5823.7
22/01/2017	00:15	1758	0	663.2	312.8	372.9	1182	0	13.6	769.9	688	0	0	0	5740
22/01/2017	00:30	1757.2	0	559.6	309.2	367.5	1160.4	0	13.8	770.1	700.3	0	0	0	5618.8
22/01/2017	00:45	1756.4	0	264.4	320.8	395.7	1202	0	15.4	772.8	721.3	0	0	0	5425.9
22/01/2017	01:00	1757.6	0	252.8	296	302.1	1260	0	15.5	765.8	702.8	0	0	0	5324.6
22/01/2017	01:15	1755.2	0	235.6	292.8	241.8	1269.2	0	14.9	762.1	692.2	0	0	0.1	5234.6
22/01/2017	01:30	1756.8	0	214.4	270.4	187	1268.8	0	14.9	765.9	659.8	0	0	0.1	5102.9
22/01/2017	01:45	1756.8	0	165.2	272.4	193.1	1285.2	0	14.1	770	625.7	0	0	0	5044.7
22/01/2017	02:00	1755.2	0	158.4	230.5	201.1	1479.2	0	15.1	765	613	0	0	210.7	4968.6
22/01/2017	02:15	1755.2	0	159.2	250.9	325.5	1570.4	0	14.4	767.2	601.1	0	0	532.9	4881.1
22/01/2017	02:30	1755.6	0	160	231.1	276.8	1554	0	14.7	768.9	580.7	0	0	473	4838.2
22/01/2017	02:45	1757.2	0	162.8	218.1	218.2	1572.4	0	14.2	767.4	572.9	0	0	462.8	4788.9
22/01/2017	03:00	1754.8	0	190	243.4	259.5	1658.8	0	15.8	764.3	555.6	0	0	667.3	4745
22/01/2017	03:15	1755.6	0	162.4	258.5	266	1693.2	0	15.4	765.7	543.7	0	0	718.4	4712.8
22/01/2017	03:30	1754.8	0	174.8	278.5	277.5	1693.2	0	14.1	763.6	538.3	0	0	796.4	4667.9
22/01/2017	03:45	1757.2	0	221.2	261.4	250.4	1676.8	0	14.1	762.1	548.1	0	0	832.7	4628.6
22/01/2017	04:00	1758	0	359.2	207.9	228.3	1611.2	0	14.1	764.7	555.1	0	0	832.2	4636.2
22/01/2017	04:15	1754.8	0	373.6	120.2	247	1650.8	0	13.1	760.4	572.4	0	0	833.4	4629.3
22/01/2017	04:30	1755.6	0	381.6	116.5	250.8	1652.4	0	14.3	761.3	590.8	0	0	906.9	4584.9
22/01/2017	04:45	1756.8	0	423.6	136.1	247.1	1650.4	0	15.5	765.2	624.2	0	0	1036.4	4553.1

Table A. 2- Portugal demand diagram data for January 22 of 2017, provided by REN (continuation).

Data	Hora	Carvão	Fuel	Gás Natural	Albufeiras	Fios de Água	Importação	Exportação	PRE Hidráulico	PRE Térmico	PRE Eólica	PRE Fotovoltaico	PRE Ondas	Bombagem	Consumo
22/01/2017	05:00	1755.6	0	408.8	176.5	218.7	1690.4	0	13.9	762.6	647.8	0	0	1035.6	4612
22/01/2017	05:15	1755.2	0	408.4	177.8	219.4	1688.8	0	12.9	765.8	662.6	0	0	1035	4627.1
22/01/2017	05:30	1755.6	0	409.6	132.3	202.3	1667.2	0	14.1	764.2	679.5	0	0	1035.2	4561.6
22/01/2017	05:45	1757.6	0	413.2	115.1	225.5	1674	0	14.1	763.4	686.9	0	0	1014.4	4605.9
22/01/2017	06:00	1757.2	0	486.4	265.5	288.8	1502.4	0	14.1	760.6	713.7	0	0	1099.7	4664.6
22/01/2017	06:15	1756.4	0	506.8	251	244.6	1482.4	0	14.4	756.9	747.6	0	0	1125	4610.9
22/01/2017	06:30	1757.6	0	535.6	219.4	304	1485.6	0	13.6	757.9	762	0	0	1125.2	4684.9
22/01/2017	06:45	1756	0	620	204.3	283.4	1395.2	0	12.1	757.8	762	0	0	1055.2	4703.6
22/01/2017	07:00	1756.8	0	674	163.5	485.9	680	0	12.9	762.1	766.6	0	0	578.4	4693.2
22/01/2017	07:15	1756	0	702	118.2	438.3	588.8	0	13.4	754.2	778.8	0	0	447.5	4668.6
22/01/2017	07:30	1755.6	0	590.4	81.7	420.3	592.4	0	12.3	757.8	796.6	0	0	391.9	4584
22/01/2017	07:45	1755.6	0	599.6	17	464.9	589.6	0	11.9	754.9	774.4	1.5	0	381.8	4554.5
22/01/2017	08:00	1755.6	0	699.6	0.2	431.4	454	0	24	754.4	742.8	12.7	0	171.8	4665.7
22/01/2017	08:15	1754	0	686.8	0.1	401.2	409.6	0	38.6	754.2	730.3	37.3	0	25.7	4754.2
22/01/2017	08:30	1756.8	0	723.6	0.1	430	428.8	0	50.2	751.9	720.9	68	0	7.3	4891
22/01/2017	08:45	1757.2	0	830.4	35.8	443.7	381.2	0	56.6	751.5	714.7	106.1	0	0	5045.8
22/01/2017	09:00	1755.6	0	961.6	310.2	512.4	0	13.2	57.6	756	699.9	139.3	0	0.1	5150.7
22/01/2017	09:15	1754.8	0	1021.6	404.4	499.2	0	38.8	64	750.2	671.5	173.6	0	0	5271.5
22/01/2017	09:30	1755.2	0	1111.6	488	504.4	0	33.2	64.1	750.2	633.4	205.7	0	0.1	5451.8
22/01/2017	09:45	1758.4	0	1102	603	497.1	0	9.6	61.8	743.3	604.2	229.3	0	0	5560.2
22/01/2017	10:00	1754.8	0	1084.8	479.5	461.7	247.2	0	59.5	743.5	605.9	252.9	0	0	5665.4
22/01/2017	10:15	1754	0	1166.8	464.6	445.5	305.2	0	67	755.6	571	274.5	0	0	5779.8
22/01/2017	10:30	1756.4	0	1216	540.2	442.4	259.2	0	64.9	752.8	552.1	284.5	0	0.1	5844.8
22/01/2017	10:45	1757.2	0	1202.8	514.4	452	327.6	0	68.2	761.1	539	296.4	0	0	5895.4
22/01/2017	11:00	1756	0	1292.4	261.1	372.5	651.6	0	65.1	764.3	522.4	303.2	0	0	5964.5
22/01/2017	11:15	1755.2	0	1338.8	238	445.5	662	0	57.7	758.8	517.8	304.7	0	0.1	6055.3
22/01/2017	11:30	1755.2	0	1351.6	238.5	460.7	679.6	0	57.2	757.8	521.2	305.5	0	0	6103.4
22/01/2017	11:45	1758.8	0		218.4	441.8	720.4	0	53.7	758.1	542.8	306.5	0	0.1	6144.4

Table A. 3- Portugal demand diagram data for January 22 of 2017, provided by REN (continuation).

Data	Hora	Carvão	Fuel	Gás Natural	Albufeiras	Fios de Água	Importação	Exportação	PRE Hidráulico	PRE Térmico	PRE Eólica	PRE Fotovoltaico	PRE Ondas	Bombagem	Consumo
22/01/2017	12:00	1757.2	0	1256.8	0.3	348.3	1152	0	46.5	755.3	568.8	314.9	0	0	6177.2
22/01/2017	12:15	1755.6	0	1332.4	0.2	246.8	1210.8	0	49.7	761.5	588.9	311.9	0	0.1	6234.7
22/01/2017	12:30	1753.6	0	1318.4	0.2	241.2	1203.6	0	50	761.7	623.5	300.4	0	0	6230
22/01/2017	12:45	1756.8	0	1278	9.9	232.6	1184.8	0	50.5	757.7	634.6	286.1	0	0	6168.9
22/01/2017	13:00	1755.6	0	1334.8	187	232.2	885.6	0	49.5	750.6	655.1	286.7	0	0.1	6112.5
22/01/2017	13:15	1755.2	0	1244	229.9	200.9	861.2	0	45.3	754.3	668.6	278.6	0	14.6	5999.3
22/01/2017	13:30	1755.6	0	1200.4	195.6	206.3	878.4	0	42.4	754.7	683.2	262.5	0	17.9	5937.3
22/01/2017	13:45	1755.6	0	1250.8	85.1	224.1	947.6	0	42.8	758.1	713.6	252.6	0	117.3	5882.8
22/01/2017	14:00	1755.6	0	1202.4	65.3	174.6	1606.8	0	42.8	754.2	748	262.9	0	733.6	5850.5
22/01/2017	14:15	1754.4	0	1248.4	40.4	170.9	1692.8	0	43.3	756	758.7	264.6	0	894.6	5811.2
22/01/2017	14:30	1754.8	0	1223.6	40.7	175.8	1663.2	0	41.9	752.7	774.9	256.1	0	898.4	5762.7
22/01/2017	14:45	1757.6	0	1240.8	41.6	164.8	1681.6	0	39.4	757.5	764.7	242.4	0	898.6	5767.1
22/01/2017	15:00	1754.4	0	1286	57.4	130.3	1713.2	0	48.8	755.1	753.6	219.9	0	994.6	5700.6
22/01/2017	15:15	1756	0	1290.8	57.6	133.2	1686	0	52.1	754.4	767.3	202.3	0	1013.4	5659.9
22/01/2017	15:30	1753.6	0	1314	57.8	140.4	1674.8	0	51	755.2	768	189.7	0	1012.6	5665.6
22/01/2017	15:45	1755.6	0	1279.6	61.1	141.1	1554.4	0	50.5	753.8	818.6	160.8	0	911.8	5636.6
22/01/2017	16:00	1755.6	0	1382.4	308.1	220.8	316	0	46.3	755.2	831.5	134.2	0	77.6	5649.7
22/01/2017	16:15	1754	0	1355.6	368	268	153.6	0	51	758.2	849.7	118.5	0	0	5653.3
22/01/2017	16:30	1754.8	0	1325.6	360.1	263.6	166	0	53.5	759.9	879.4	92.5	0	0	5632.1
22/01/2017	16:45	1758.4	0	1452	419.7	272.6	66.4	0	52	764.8	848.8	62.5	0	0	5678.5
22/01/2017	17:00	1756.8	0	1418.4	848.9	671.1	0	656	54.3	763.4	879	27	0	0	5745.9
22/01/2017	17:15	1754.8	0	1459.2	786.2	782.4	0	700.8	57.1	762.8	946	9.3	0	0	5839.7
22/01/2017	17:30	1756	0	1574.4	772.9	813.2	0	690.8	58.1	759.8	1006.1	0.8	0	0	6038.9
22/01/2017	17:45	1757.2	0	1634	846	893.8	0	673.2	57	757.4	1093.2	0	0	0	6353.5
22/01/2017	18:00	1754.8	0	1622	1091.7	979.3	0	715.2	58.2	757.3	1174.1	0	0	0	6710.2
22/01/2017	18:15	1755.2	0	1783.6	1093.3	998.5	0	732.8	65.5	758.7	1249.1	0	0	0	6959.9
22/01/2017	18:30	1754	0	1784	1106.5	983.4	0	736.4	75.3	759.2	1307.9	0	0	0	7022.1
22/01/2017	18:45	1757.2	0	1812.8	1105.5	988.9	0	709.2	83.6	756.8	1320.5	0	0	0	7105

Table A. 4- Portugal demand diagram data for January 22 of 2017, provided by REN (continuation).

Data	Hora	Carvão	Fuel	Gás Natural	Albufeiras	Fios de Água	Importação	Exportação	PRE Hidráulico	PRE Térmico	PRE Eólica	PRE Fotovoltaico	PRE Ondas	Bombagem	Consumo
22/01/2017	19:00	1754.8	0	1792.8	1163	948.9	0	610	82.5	765.2	1350.5	0	0	0	7237.8
22/01/2017	19:15	1755.2	0	1760.4	1171.6	947.4	0	572.4	76.9	765.3	1389.4	0	0	0	7284.3
22/01/2017	19:30	1756.4	0	1804	1172	954.3	0	580.8	74.2	757.1	1403.8	0	0	0	7331.1
22/01/2017	19:45	1754	0	1812.8	1167.5	950	0	514.4	78.1	758.1	1425.2	0	0	0	7421.8
22/01/2017	20:00	1756	0	1588.4	1049.1	757.3	0	4.4	80.8	763.6	1422.1	0	0	0	7402.9
22/01/2017	20:15	1754.8	0	1621.6	959.3	732.2	67.6	0	77.3	761.7	1438	0	0	0	7402.8
22/01/2017	20:30	1754.4	0	1602.4	919.1	724.3	72	0	79.2	756.5	1465.3	0	0	0	7362.8
22/01/2017	20:45	1757.2	0	1508	930.3	690.2	65.6	0	79.3	758.9	1517.1	0	0	0	7296
22/01/2017	21:00	1752.8	0	1455.6	918.3	630.5	96.4	0	78.8	760.6	1541.7	0	0	0	7224.9
22/01/2017	21:15	1754.8	0	1355.6	909.3	622.2	128.4	0	76.9	761.8	1577.2	0	0	0	7175.6
22/01/2017	21:30	1756	0	1287.2	927	579.4	111.6	0	69.6	760.2	1561	0	0	0	7042.4
22/01/2017	21:45	1758.8	0	1347.2	808.9	572.3	143.2	0	59.9	765.8	1559.9	0	0	0	7005.4
22/01/2017	22:00	1757.2	0	1658	318.9	500.6	301.2	0	32.2	766	1618.9	0	0	0	6942
22/01/2017	22:15	1756	0	1496	266.4	468.7	341.6	0	20.4	766.2	1665.7	0	0	0	6769.7
22/01/2017	22:30	1756.8	0	1326.8	270.9	458.5	335.6	0	17	775.3	1693.5	0	0	0	6623
22/01/2017	22:45	1756.4	0	1168	277.1	456.6	386	0	16.7	772.3	1772.2	0	0	47.6	6538.2
22/01/2017	23:00	1756.4	0	955.6	307.7	480.4	602	0	14.8	779	1820.9	0	0	413	6285.6
22/01/2017	23:15	1756	0	828.8	286.3	453.8	670.4	0	13	778.1	1835	0	0	476.4	6126
22/01/2017	23:30	1755.2	0	821.6	238.4	456.5	656.4	0	12.8	777	1826.9	0	0	507.4	6013.8
22/01/2017	23:45	1756.4	0	675.6	222.5	370.4	693.6	0	11.9	771.4	1844.3	0	0	569.2	5753.6