

Article

Analysis of Fossil Fuel Energy Consumption and Environmental Impacts in European Countries [†]

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[†] This paper is an extension of the paper presented in ICEER2018 and published in Energy Procedia, vol. 153.

Received: 15 January 2019; Accepted: 8 March 2019; Published: 13 March 2019



Abstract: The use of fossil fuels as the main source of energy for most countries has caused several negative environmental impacts, such as global warming and air pollution. Air pollution causes many health problems, causing social and economic negative effects. Worldwide efforts are being made to avoid global warming consequences through the establishment of international agreements that then lead to local policies adapted to the development of each signing nation. In addition, there is a depletion of nonrenewable resources which may be scarce or nonexistent in future generations. The preservation of resources, which is a common goal of the Circular Economy strategy and of sustainable development, is not being accomplished nowadays. In this work, the calculation of indicators and mathematical and statistical analysis were applied to clarify and evidence the trends, provide information for the decision-making process, and increase public awareness. The fact that European countries do not possess abundant reserves of fossil fuels will not change, but the results of this analysis can evolve in the future. In this work, fossil fuel energy consumption, fossil fuel depletion, and their relationship with other variables, such as energy dependence and share of renewable energy in gross final energy consumption, were analyzed for 29 European countries. Furthermore, it was possible to conclude that many European countries still depend heavily on fossil fuels. Significant differences were not found in what concerns gross inland consumption per capita when the Kruskal–Wallis test was applied. It was possible to estimate that by 2050 (considering Jazz scenario) it will only remain approximately 14% of oil proven reserves, 72% of coal proven reserves and 18% of gas proven reserves. Given the small reserves of European countries on fossil fuels, if they need to use them, they will fast disappear.

Keywords: fossil fuels; low carbon energy systems; sustainable energy; sustainable development

1. Introduction

Most countries' energy systems, either developed or in development, are based on fossil fuels [1,2]. In spite of their qualities, e.g., good operational control in thermal plants [3], their use has many problems which have been analyzed and addressed in many studies [4]. These problems, such as the environmental impacts, scarcity, supply risk, and instability of prices and markets, put fossil fuels at the center of the shift to low carbon economies. Khan et al. [5] found that, in Pakistan, there is a strong relationship between energy consumption, air pollution, water resources, and natural resource rents. Zheng et al. [6] used panel data regression analysis on a sample of 26 Chinese provinces and

four centrally-controlled municipalities in the period from 2002 to 2011 and found empirical support for the positive impacts of provincial energy saving regulations and two environmental standards on the improvement of local air quality.

The use of fossil fuels is responsible for environmental problems such as global warming and air pollution, which cause health problems and affect the quality of life of populations. Lott et al. [7] concluded that by applying adequate changes in technology for residential heating, the UK would meet its decarbonization targets by 2050, and there would be a 40% and 45% decrease in PM₁₀ (Particulate matter with a diameter less than 10 µm) and PM_{2.5} (Particulate matter with a diameter less than 2.5 µm) pollution, respectively, between 2010 and 2050. Contrarily, limited change in the pollution profile for transportation would be observed if the established policy strategies were applied in that sector. Li et al. [8] concluded that Chinese government policy plays a major role in the long-term and more permanent SO₂ emission decline, through modification of industrial structure, change to cleaner energy sources, population growth limitation, and regulation of the number and emissions of vehicles. The reforms introduced in the Beijing economic structure, aiming to decrease the ratio of secondary industry, show that the policies implemented by the government are the major driver to improve air quality. Zhang et al. [9] analyzed the difference between the effects of trade and trade-related emissions on premature deaths attributable to air pollution in three regions of China and concluded that there is a strong and broad impact of domestic trade on regional air quality. This justifies the need for a comprehensive consideration of supply chains in designing policy to mitigate the negative health impacts of air pollution in China.

Besides the environmental and health problems, fossil fuels are unevenly distributed, which increases the concerns about energy security due to their key role in today's energy production systems [10]. Moreover, they are nonrenewable resources which raises the problem of their availability for this and future generations. Their complete depletion should be avoided, thus contributing to the decrease in the environmental impact in the corresponding impact category. The instability of markets and prices is also a drawback in their use, causing negative economic impacts.

All the above-mentioned issues contribute to today's unsustainable energy systems and to the quest for new solutions that will reduce the economic, social, and environmental negative impacts of energy systems, thus increasing sustainability. Achieving sustainable energy systems still remains a challenge for the majority of countries, in spite of the efforts made by governments, international agencies, and other stakeholders. In the last few decades, new policies have been implemented and incentives for renewable energy have been granted through support mechanisms, for example, feed-in-tariffs. Many other strategies, such as demand side measures and smart grids, have been addressed to overcome the challenges that a change to low carbon energy systems create [11,12].

In order to verify if the pathways chosen are being effective, it is necessary to find ways of evaluating energy systems and energy policies. The approaches used usually define a set of indicators to be applied, and then the performance of each country can be assessed and compared. The goal of such a set of indicators is to evaluate the sustainability of energy systems and can include indicators about energy efficiency, energy availability, and renewable energy. Some of these are applicable on a global scale and others in a local area, such as a country [13,14]. Economical aspects, such as subsidies, can directly affect the selected indicators and the progress toward more sustainable energy systems [15,16]. Projection and scenarios for the future are also techniques frequently used, because environmental concerns (greenhouse gas emissions), social issues (electrification rate and accessibility to energy at fair prices), and energy policies and investments are very closely linked [17–19]. Technological advances and innovation can also contribute to new solutions and make new resources available. All these issues are necessary to define possible pathways in the future.

European countries have been at the edge of these changes and renewable energy sources are a key aspect in new energy policy and projected pathways [20]. However, fossil fuels are still crucial in energy systems [21]. This work analyzes fossil fuel information and applies statistical tools to show the present situation in European countries. Although there is information available in open

literature, it has not been analyzed under such a mathematical approach. The calculation of indicators, merit figures, and mathematical and statistical analysis are mainly used to clarify and emphasize the trends, problems, and provide condensed information that can be useful in the decision-making process. Therefore, this work analyzes fossil fuel energy consumption (oil, solid fuels, and gas), fossil fuel depletion in European countries, and their relationship with other variables, such as energy dependence and share of renewable energy. It also analyzes the progress made by individual European countries toward a low carbon energy system. Projections for the future and their impacts are also addressed in this paper. A Kruskal–Wallis test was applied to assess the effect of several factors on gross inland consumption per capita.

2. Materials and Methods

Energy systems are changing, and it is important to quantify and assess those variations, measuring the progress toward the established goals. Indicators can be a useful tool to achieve that purpose. These indicators can analyze energy systems globally, such as the energy mix for a given country, considering the different sources of energy: fossil (fuel, coal, and gas), nuclear, biofuels and waste, renewable (hydro, solar, wind, geothermal, etc.), or parts of the energy system (renewable energy sources) [22]. Another indicator is energy dependence, which is important because it can significantly affect the development of countries, since it increases their vulnerability to price instability and supply ruptures. Share of renewable energy in the gross final energy consumption is an important indicator, since it can represent the pathway to lower carbon energy systems. Concerning fossil fuels, there are some indicators that are very important, such as the fossil fuel energy mix, fossil fuel energy consumption, and fossil fuel depletion.

These indicators can be defined as follows:

- Energy mix: contribution of each source of energy to total energy;
- Energy dependence: the percentage of imports in total energy consumption;
- Share of renewable energy: the percentage of renewable energy in gross final energy consumption [22];
- Fossil fuel energy mix: the contribution of each fossil fuel source of energy to the fossil energy;
- Fossil fuel energy consumption: the quotient between the usage of fossil fuels (oil, solid fuels, and gas) and gross inland energy consumption (Equation (1)):

$$\text{Fossil fuel energy consumption (\%)} = \frac{E_{\text{solid fuels}} + E_{\text{oil}} + E_{\text{gas}}}{\text{Gross inland consumption}} \quad (1)$$

where $E_{\text{solid fuels}}$ is the energy consumption from solid fuels, $E_{\text{total petroleum products}}$ is the energy consumption from petroleum products, and E_{gas} is the energy consumption from gas.

- Depletion of fossil fuels: the quotient between fossil fuel reserves (proven) and gross annual production (Equation (2)). There are three indicators, one for oil, one for gas, and one for coal:

$$\text{Fossil fuel depletion (years)} = \frac{\text{Fossil fuel reserves}}{\text{Gross annual production}} \quad (2)$$

Data, relative to the year 2016, were gathered for several European countries from Eurostat [23] and used in this study. Furthermore, statistical data from BP were used, dated from the year 2017 [24].

Two of the mathematical tools (the software used was SPSS Statistics 25) used in this work were Pearson correlation and Spearman's correlation [25]. Pearson r correlation is applied to assess a linear relation between two variables. Pearson correlation is more reliable when the distribution is normal; however, since there are different degrees of violation of normality, both methods were applied. Spearman's correlation also assesses the relationship between two variables, yet it is a nonparametric method and does not require a normal distribution. Significant correlation between variables exist

when the p value is lower than 0.05. If variables are negatively correlated, this means that the higher one of them is the lower the other one will be. To assess normality, the Shapiro–Wilk test was used. Another statistical tool used was the Kruskal–Wallis test [26]. This is a nonparametric test that is used to compare two or more independent groups. It can be used to determine if there are statistically significant differences between groups (two or more) of a categorical independent variable on a continuous dependent variable. In this study, four independent variables were considered, namely energy dependence, fossil fuel energy consumption, share of renewable energy, and fossil fuel reserves, and the dependent variable was the Gross Inland Consumption (GIC) per capita.

3. Results and Discussion

3.1. Fossil Fuel Energy Mix for European Countries

Figure 1 shows the fossil fuel energy mix for the European Union countries.

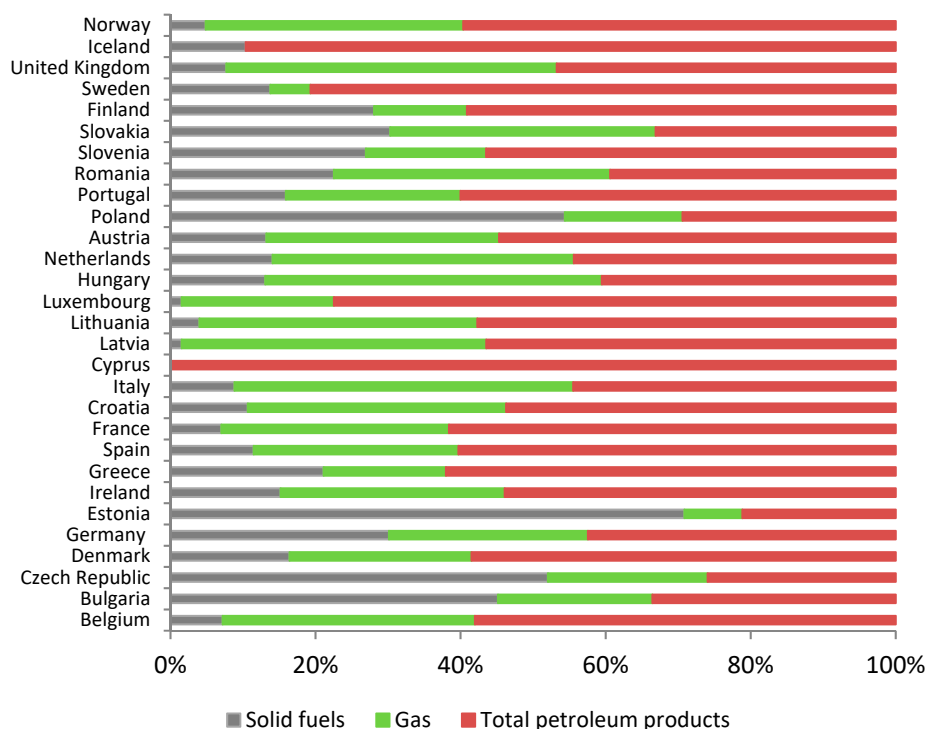


Figure 1. Fossil fuel energy mix in the European Union countries (adapted from [21]).

The indicators were calculated using data (2016) that were gathered for several European countries from Eurostat [23]. Considering the energy consumption of oil, solid fuels, and gas in the selected European countries, it is possible to conclude that in most of the countries considered the oil presents the highest percentage. Only in four countries, solid fuels present a higher percentage, namely Bulgaria, the Czech Republic, Estonia, and Poland, which is due to the local availability of solid fuels. In Italy, Hungary, and Slovakia, gas presents the highest percentage. In many countries the solid fuels' percentage is very small, as can be seen in Figure 1, which is a positive aspect since solid fuels are recognized as having more severe environmental and social negative impacts. The European directives issued toward the use of cleaner sources of energy can be indicated as a factor that contributed to this situation [27].

3.2. Fossil Fuel Energy Consumption Indicator

The fossil fuel energy consumption (FFEC) was calculated for the 29 selected European countries (shown in Figure 2).

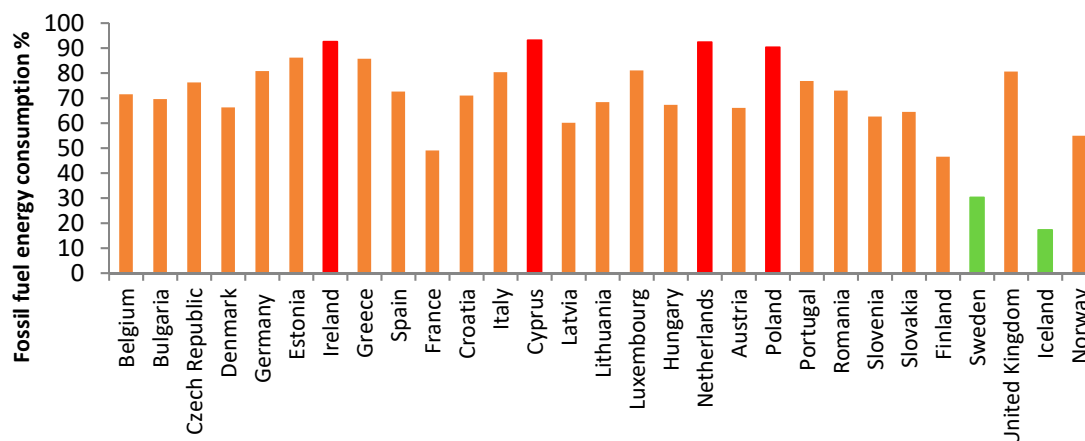


Figure 2. Fossil fuel energy consumption indicator in the European Union countries.

It is possible to conclude that Iceland and Sweden are the only countries where the FFEC indicator is lower than 40% (to emphasize this fact their bars are green). In fact, Iceland has a value even lower than 20%. There are only three countries with FFEC indicator values between 40% and 60%, namely France, Finland, and Norway. All the other countries have FFEC values above 60%. Ireland, Cyprus, Poland, and the Netherlands have values higher than 90% for this indicator (due to the high value of the indicator the bars are red to emphasize this fact), which can be attributed to a higher local availability of fossil fuels.

3.3. Fossil Fuel Depletion

The European countries do not possess many fossil fuel resources, as can be verified in Table 1. Figure 3 presents oil, coal, and gas depletion for the world and some European countries (data from [24]). Eurasian countries, such as the Russian Federation, were not considered in this analysis. As shown in Figure 3, the result for coal depletion in Spain is very high (>500 years), because its production is very low. Conversely, Poland has much higher reserves of coal than Spain, but its production is 75 times higher, which results in less years to fossil fuel depletion in Poland.

Table 1. Fossil fuel proven reserves [24] in European countries.

Country	Oil Reserves (Million Barrels)	Coal Reserves (Million Tonnes)	Gas Reserves (Billion Cubic Meters)
Bulgaria	0	2366	0
Czech Republic	0	3676	0
Denmark	400	0	14
Germany	0	36,212	37
Greece	0	2876	0
Hungary	0	2909	0
Italy	500	0	37
Netherlands	0	0	700
Norway	7600	0	1800
Poland	0	24,161	100
Romania	600	291	100
Spain	0	1187	0
United Kingdom	2500	70	200

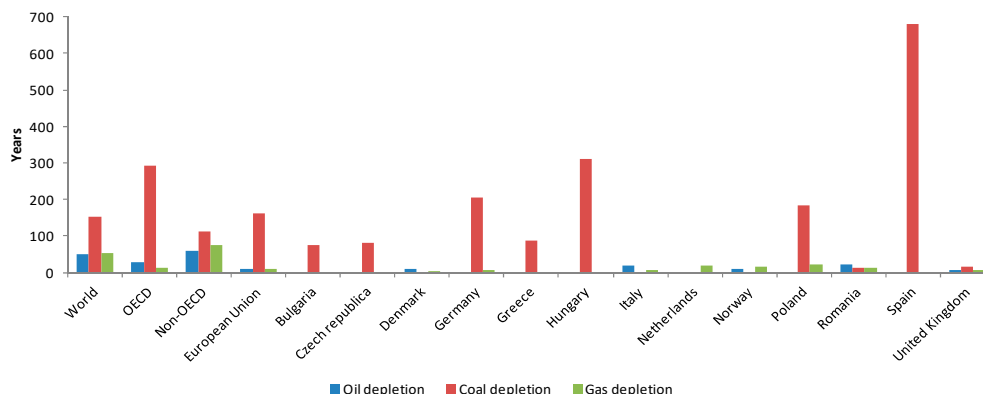


Figure 3. Fossil fuel depletion.

3.4. Fossil Fuel Energy Consumption and Other Variables

Another stage of this work was to analyze the relationship of fossil fuel energy consumption (FFEC) and fossil fuel reserves (FFR) with other variables such as energy dependence (ED, calculated as the percentage of imports in total energy consumption) and share of renewable energy (SRE) in gross final energy consumption (data from [23]). Norway was excluded from this analysis because the value for energy dependence was very different from all the other countries' values, and that could have significantly affected the results.

Table 2 presents the results of a correlation analysis made by two methods, one that uses the Pearson correlation and the other that uses Spearman's correlation. A significant negative correlation was found for energy dependence and share of renewable energy and fossil fuel energy consumption and share of renewable energy by both methods ($p < 0.05$). Since fossil fuel energy consumption and share of renewable energy are negatively correlated, this means that the higher the share of renewable energy the lower the fossil fuel energy consumption. The same can be said of the correlation concerning energy dependence and share of renewable energy. Fossil fuel reserves presented a significant positive correlation with fossil fuel energy consumption in the Spearman's correlation, which has some justification, because the ownership of fossil fuel reserves may induce some fossil fuel consumption since it is a resource that the country possesses. Table 3 presents the confidence intervals (for 95%) for these two significant Pearson correlations.

GIC (gross final energy consumption per capita in GJ) presented a significant negative correlation with fossil fuel energy consumption and a positive one with share of renewable energy when the Pearson correlation was used (Table 2). This should be carefully followed, because it means that the higher the share of renewable energy the higher the GIC per capita. By applying the Shapiro–Wilk test for assessing normality, it was possible to conclude that all hypotheses of normal distribution were rejected except for energy dependency, so the Spearman's correlations were more reliable. When Norway was included, all hypotheses of normal distribution were rejected.

Most countries presented a high fossil fuel energy consumption and a low share of renewable energy. The exceptions were Iceland and Sweden, which presented a low fossil fuel energy consumption and a high share of renewable energy, and Norway, which presented high percentages for both variables. In Iceland, electricity came from hydro (73%) and geothermal (27%) sources in 2016, and the majority of houses were heated using geothermal energy. Iceland still presented a high dependence on fossil fuels when considering transportation and fishing [28,29]. In 2016 in Sweden, almost 98% of electricity came from nuclear and renewable (40% from hydroelectric power), and its share of renewable energy was the highest in the European Union [23,30]. In Norway, for the same year, electricity was mainly generated by hydro resources (97%). However, Norway is a supplier of oil and gas, since it has significant hydrocarbon resources [31]. Due to this, Norway was excluded from the correlation analysis since the value for energy dependence is very different from the other countries' values.

Table 2. Correlation between variables.

		ED	FFEC	SRE	FFR	GIC			ED	FFEC	SRE	FFR	GIC
ED	Pearson	1	0.353	−0.472 *	−0.037	−0.210	Spearman's	1.000	0.279	−0.407 *	−0.192	−0.181	
	Sig. (2-tailed)	-	0.065	0.011	0.851	0.283		Sig. (2-tailed)	-	0.151	0.032	0.327	0.356
	N	28	28	28	28	28		N	28	28	28	28	28
FFEC	Pearson	0.353	1	−0.820 **	0.250	−0.592 **	Spearman's	0.279	1.000	−0.663 **	0.381 *	−0.141	
	Sig. (2-tailed)	0.065	-	0.000	0.200	0.001		Sig. (2-tailed)	0.151	-	0.000	0.046	0.474
	N	28	28	28	28	28		N	28	28	28	28	28
SRE	Pearson	−0.472 *	−0.820 **	1	−0.204	0.583 **	Spearman's	−0.407 *	−0.663 **	1.000	−0.353	−0.059	
	Sig. (2-tailed)	0.011	0.000	-	0.299	0.001		Sig. (2-tailed)	0.032	0.000		0.066	0.766
	N	28	28	28	28	28		N	28	28	28	28	28
FFR	Pearson	−0.037	0.250	−0.204	1	−0.078	Spearman's	−0.192	0.381 *	−0.353	1.000	−0.239	
	Sig. (2-tailed)	0.851	0.200	0.299		0.694		Sig. (2-tailed)	0.327	0.046	0.066	-	0.221
	N	28	28	28	28	28		N	28	28	28	28	28
GIC	Pearson	−0.210	−0.592 **	0.583 **	−0.078	1	Spearman's	−0.181	−0.141	−0.059	−0.239	1.000	
	Sig. (2-tailed)	0.283	0.001	0.001	0.694			Sig. (2-tailed)	0.356	0.474	0.766	0.221	
	N	28	28	28	28	28		N	28	28	28	28	28

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). Sig.-Significance N- number of countries

Table 3. Confidence intervals for correlation.

r	n	Lower Bound	Upper Bound
−0.472	28	−0.7185	−0.1201
−0.820	28	−0.9136	−0.6439

The significant negative correlations observed between fossil fuel energy consumption and share of renewable energy and energy dependence and share of renewable energy show that most European countries have a long pathway ahead in order to achieve low carbon energy systems. It is definitely necessary to increase the share of renewable energy and continue with the incentives for renewable energy. The exceptions to this trend described above show that it is necessary that each country should choose its energy mix according to its own local characteristics, making the most of its natural renewable resources.

Nuclear energy is low carbon energy; however, it presents several disadvantages, such as the consequences of nuclear accidents or the management of nuclear wastes, which impact on the environment. These aspects can mask the positive characteristics of this kind of energy and can be an obstacle to its implementation or continuity, especially when comparing it with renewable energy.

3.5. Analysis of Gross Inland Consumption per Capita Using Kruskal–Wallis Test

In the Kruskal–Wallis test, four independent variables were considered, namely energy dependence, fossil fuel energy consumption, share of renewable energy, and fossil fuel reserves, and the GIC per capita was the dependent variable. The results for the Kruskal–Wallis test are presented in Table 4. Analyzing the results, it is possible to conclude that significant differences ($p < 0.05$) were found for share of renewable energy. For all other variables, statistical differences were not found. Norway was not considered in the first test because its value for energy dependence is completely different from the values of the other countries, and it could have significantly affected the results.

Table 4. Kruskal–Wallis results.

Groups	GIC Per Capita (GJ)				
	Number	Mean	SD	Kruskal–Wallis Test	
ED (%)	>75;	5	169.3774	88.16911	0.781
	50–75;	8	123.8830	27.28434	
	25–50;	11	149.388	55.27619	
	<25	4	274.536	291.03302	
FFEC (TJ)	>75;	12	150.1715	60.56168	0.070
	50–75;	13	128.6138	47.26717	
	25–50;	3	209.8192	54.04421	
	<25	1	703.8394		
SRE (%)	50–75;	3	380.3492	280.30720	0.030
	25–50;	9	132.9515	63.98637	
	<25	17	145.2778	52.64289	
FFR (TJ)	>10 million;	11	133.5069	47.66839	0.434
	1–10 million;	2	117.3098	14.85270	
	<1 million	16	194.0098	149.6713	

The results of this statistical test seem to corroborate the link between GIC per capita and share of renewable energy. When the share of renewable energy is higher, between 50% and 75%, the average GIC is much higher than in the other groups. Looking closer at the data, it is possible to conclude that this result was obtained due to Iceland. If Iceland is excluded, no significant differences are found—its GIC is more than two times the next higher value.

3.6. Fossil Fuel Energy Usage Projection to 2050

According to the scenarios developed by the World Energy Council [20], the primary energy supply in 2050 will be 879 EJ/y in the Jazz scenario and 696 EJ/y in the Symphony scenario, where the share of fossil fuels in the energy mix will be 79% and 59%, respectively. Jazz gives priority to achieving individual access and affordability of energy through economic growth, and Symphony gives priority on achieving environmental sustainability through internationally coordinated policies and practices [20]. In the Jazz scenario, the share of fossil fuels is similar to the present share of fossil fuels [22]. In this work, the impact on the proven reserves of fossil fuels was estimated by calculating an annual average increase in energy which will be reflected in an equal increase of the energy production rate in the different fossil fuels (since the energy mix is similar). The average annual increase in the Jazz scenario was 1.2% and that increase was considered in the production of energy from oil, coal, and gas taking into consideration the energy content of each fossil fuel [24]. For solid fuels an average value was considered between hard coal and lignite and sub-bituminous coal. It was possible to conclude that by 2050 it will only remain approximately 14% of oil proven reserves, 72% of coal proven reserves and 18% of gas proven reserves. Given the small reserves of European countries, it means that if they need to use their fossil fuel reserves, they will rapidly disappear. However, technological advances in several areas can help to find new reserves/resources and also help to increase the efficiency in energy use. Biofuels are also being studied to find substitutes for some products produced from fossil fuels [32,33]. In addition, the increase in primary energy in Europe will be lower than in other regions of the world. Some studies are also evaluating the role of renewable energy and the possibility of having a European energy system based on 100% renewable sources [34–37].

4. Conclusions

One of the conclusions of this work is that many European countries are still heavily dependent on fossil fuels. The values for the fossil fuel energy consumption indicator is higher than 60% for most countries, which corresponds to 24 countries out of the 29 European countries analyzed in this study. Additionally, 10 countries present values higher than 80%, which includes countries, such as Germany and the United Kingdom, that are considered leaders in the shift to renewable energy. This means that, in spite of the efforts and changes in energy policies made by European countries, there is still a long way ahead to achieve low carbon energy systems. Moreover, fossil fuels do not exist in quantity in most of the European countries. Solid fuels present the highest availability, but, as is known, they present more severe environmental impacts. However, probably due to European legislation, the fossil fuel energy mix of the European countries studied does not depend heavily on solid fuels, which is a positive aspect from an environmental and social perspective. The positive factor is that the renewable energy and fossil fuel energy consumption indicators are negatively correlated, the higher the first the lower the other. This work also revealed that a correlation between gross inland consumption (GIC) per capita and share of renewable energy should be carefully followed and further studied in the future, since it seems that they could be positively correlated. The indicators that were calculated and the mathematical and statistical analysis performed all clarified and highlighted the present trends. It was possible to estimate that by 2050 (considering Jazz scenario) it will only remain approximately 14% of oil proven reserves, 72% of coal proven reserves and 18% of gas proven reserves. If European countries need to use their limited fossil fuel reserves, they will fast disappear. This work provided relevant information for the decision-making process and to increase awareness in a comprehensive way. Renewable energy is a key issue to decrease fossil fuel usage and to the shift to low carbon energy systems.

Author Contributions: Conceptualization and methodology, F.M.; writing—original draft preparation, F.M., C.F., and M.S.; writing—review and editing, N.C.

Funding: This work was financially supported by project UID/EQU/00511/2019—Laboratory for Process Engineering, Environment, Biotechnology and Energy (LEPABE) funded by national funds through FCT/MCTES (PIDDAC), by project UID/EQU/00305/2013—Center for Innovation in Engineering and Industrial Technology

(CIETI), and by European Union (FEDER funds through COMPETE) and National Funds (FCT) through project UID/QUI/50006/2013.

Conflicts of Interest: The authors declare no conflict of interest.

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