Trabajo Fin de Máster

Relation between Energy production and Water in Spain. A particular case for Waste Water Treatment Plants in Granada.

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Abstract

In recent years the relationship between the energy produced and the amount of fresh water needed in the process is attracting increasing attention. In this work we have carried out a systematic study of that relationship using the Water Footprint (WF) approach. We have compared the contribution of each energy source, distinguishing between renewable and non-renewable, in the production of electricity is Spain during the last three decades, to later relate each energy source to its corresponding consumptive Water Footprint. For comparative purposes, we have also extended our analysis to other European countries and to the region of Andalusia. We also performed a study over a sample of six different-type Waste Water Treatment Plants (WWTP) in the province of Granada to estimate the Used Fresh Water (UFW) along the full chain of treating water in the plants.

Keywords— Water Footprint, WF, Used Fresh Water, UFW, Waste Water Treatment Plats, WWTP

Resumen

En los últimos años la relación entre energía producida y cantidad de agua dulce necesaria en el proceso está atrayendo cada vez más interés. En este trabajo hemos llevado a cabo un estudio sistemático de esa relación utilizando el método de la Huella Hídrica (WF). Hemos comparado la contribución de cada fuente de energía, distinguiendo entre renovables y no renovables, en la producción de electricidad en España durante las tres últimas décadas, para luego relacionar cada fuente de energía con su correspondiente Huella Hídrica consumida. Con fines comparativos, también hemos extendido nuestro análisis a otros países europeos y a la región de Andalucía. También hemos realizado un estudio sobre una muestra de seis Plantas de Tratamiento de Aguas Residuales (WWTP), de diferentes tipos, en la provincia de Granada con el objetivo de estimar el Agua Dulce Usada (UFW) a lo largo de toda la cadena de tratamiento del agua en dichas plantas.

Keywords— Huella Hídrica, WF, Agua Dulce Usada, UFW, Estación Depuradora de Aguas Residuales, WWTP

Contents

1 Introduction

Water is life, sustaining ecosystems and regulating our climate, but it is a limited resource. Of all the fresh water on Earth, only 1% is accessible for direct human use. It is therefore essential that all countries know the value of one of their most precious and scarce resources.

By the global warming warnings, it is very well known that the scarcity of water is elevating day by day. The availability of sufficient quality fresh water is an important issue on present policy agenda in European Union (EU) and in the world. In the year 2000, the EU introduced the Water Framework Directive (WFD), Directive 2000/60/EC [1], representing the most important and comprehensive part of EU legislation ever approved in water policy. In Spain the WFD was immediately carried out through Law 62/2003, of December 30 [2]. The WFD significantly increased the control of the water quality and water discharges to the water basins and rivers, elevating the areas declared sensitive due to the risk of eutrophication and the direct discharges of waste water. As a consequence, for example, the already installed Waste Water Treatment Plants (WWTP) elevated drastically their requirement in water discharge quality.

According to the hispagua article [3], around 500 WWTP were installed in the early 1990s, of which only 40% met the ecological requirements. Following the implementation of the WFD the number of WWTP increased considerably and now around 2533 are installed throughout Spain, according to the database of the National Water Quality Plan (NWQP) [4]. The availability of water of sufficient quality is an important issue. Understanding the relationship between the water needed for energy production and the energy needed for water supply is therefore essential to understand the balance of water used throughout the water treatment chain. The modernisation and installations of the new WWTP have led Spain to increase the associated energy expenditure. Energy and water are very much interlinked, so that achieving their supply for all countries requires a nexus approach. In 2012, the International Energy Agency (IEA) recognised the importance of the relationship between water and energy. In its annual report of the World Energy Outlook, IEA projects a rise of 85% in water use for energy production over the next twenty years, related to the expected shift towards more water-intensive power generation and the expanding use of biofuels.

From the point of view of energy production, water is essential. It is used, for example, in extraction, processing and transportation of fuels, to grow biomass for biofuel, also when coal is mined, water is needed for coal washing (coal preparation), dust suppression and machine cooling. At the same time, water can be produced from the mines, which is often polluted and needs to be treated before discharge or recycling. For oil, when the pressure in an oil reserve decreases, water can be injected into the wells to drive the oil out. For uranium, consumption of water is needed, when the uranium ore is mined and converted to uranium fluoride, but it occurs most significantly in the process of enrichment of uranium. In addition, water is also used to produce energy in Thermal and Nuclear power plants (TPP/NPP) and Combined Heat and Power plants (CHP).

The fastest growing form of energy is electricity production. Figure 1 shows the increase in electricity production (in units of GWh) in Spain from 1990-2018. It distinguishes between non-renewable (TPP/NPP/CHP) and renewable sources, hydro-power (hydroelectricity), solar energy (captured through either concentrated solar power (CSP) or photo-voltaic (PV systems), wind energy (wind electricity) and burning biomass (bio-electricity).

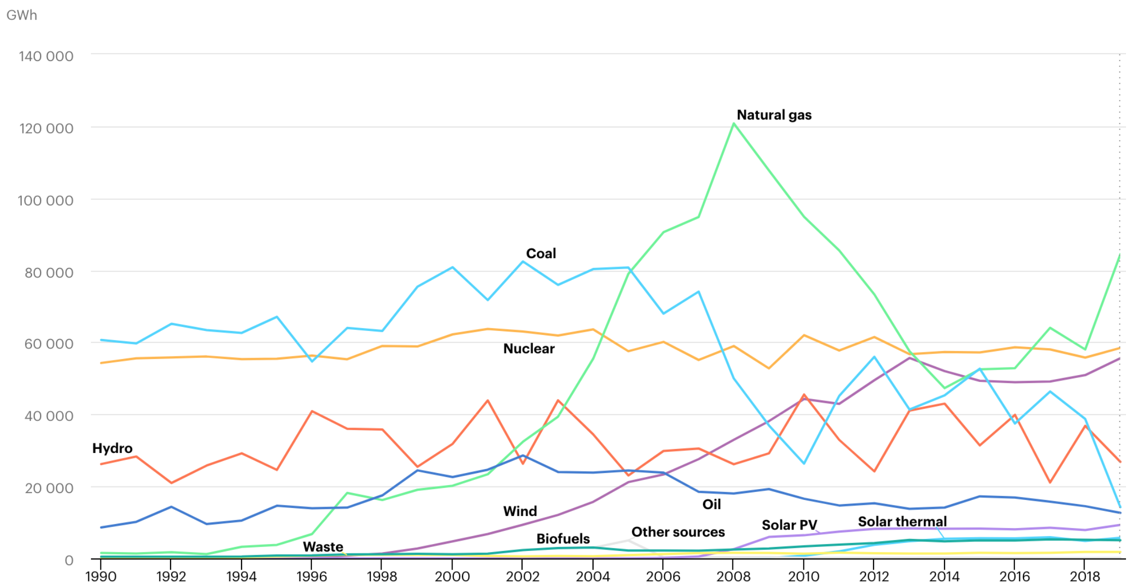

Figure 1: Increase in electricity production in Spain from 1990-2018, provided by the International Energy Agency (IEA) [5].

The consume of electricity is everywhere, including Waste Water Treatment Plants. Actually, the WWTP present quite high total electricity demand. In United States it has been estimated that roughly 4% of the electricity demand is employed for potabilization and distribution of water as well as collection and treatment of wastewater. In Spain, some studies demonstrate that domestic and industrial water cycles account for 2-3% of total electric energy consumption, and considering water management and agricultural demand, could reach 4-5%. The 2533 WWTP currently running in Spain generate a flow of 3375 hm^3 of treated wastewater per year. In the case of *Andalucia* region, according to National Plan for Water Quality database, around 545 WWTP are registered, which generate 520.07 hm^3/year of recovered water.

The main purpose of my Master Thesis Work is to investigate the interlink between the electricity production and the used freshwater in the process. We will put a particular interest in the case of Waste Water Treatment Plants, with our case-study in the province of Granada. In this last case, we want to answer the question: *How much fresh water do we use to treat the water?* To develop our studies we have applied a method called "Water Footprint" (WF) [6], which represents a crucial part of our study.

In 2002 the Water Footprint concept was introduced by professor Arjen Hoekstra, in order to have a consumption-based indicator of water use, that could provide useful information in addition to the traditional production-sector-based indicators of water use. The WF approach considers the place where water is consumed, the type of water used and when it is used. In fact, WF measurements can be computed for given areas, regions or even for nations. In addition, it introduces the concept of blue, green and gray water footprint: i) the concept of blue WF measures the consumptive use of surface and groundwater, water from lakes, reservoirs and river basins, ii) the concept of green WF is the amount of water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants, iii) the concept of grey WF, used as an indicator of water pollution, represents the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards.

To answer the question mentioned above, the new term of Used Fresh Water (UFW), expressed in m^3/m^3, has been introduced. It shows the amount of fresh water used on the energy production phase in units of Kwh/m^3, related to the total energy consumed per volume of treated water in WWTP, in units of m^3/Kwh.

Work plan. This Master Thesis is organised as follows:

- We start in Section 2 with a brief introduction about the methodology to estimate the Water Footprint in the electricity production for different energy sources.
- In Section 3 we describe the main energy sources in Spain and calculate the WF associated to each of them. For completeness, and by way of comparison, we continue in Subsection 3.3 describing briefly the ”energy source - WF” relationship for different EU countries with very different sources of energy contributing to their electricity production.
- We continue in Section 4 studying the particular case of the region of Andalusia.
- An finally, in Section 5 we focuss in the Waste Water Treatment Plants in the province of Granada, to study the balance between ”used fresh water versus treated water” in these systems.

2 Methodology

2.1 Water Footprint of electricity for different energy technologies and sources

The water footprint of electricity, named by WF, and expressed in units of m^3/TJ, refers to the volume of water consumed at different stages of the energy production process. The absence of data for water pollution (from mining and chemical loads from the power plants) prevented us to include the grey WF component in our study, limiting us to the use of only the blue and green components, thus underestimating the total WF of electricity obtained in this work.

Water Footprint studies typically distinguish between three main stages of electricity production: fuel supply, construction and operation. The first stage is only relevant for electricity production based on coal, oil, natural gas, uranium and biodiesel. In the other cases under study (hydro, solar and wind), this is negligible or nonexistent. Therefore, in the last cases we only consider the remaining two production stages (i.e. construction and operation). The European Commission's science and knowledge service has conducted the most geographically detailed consumptive WF assessment for the EU to date, based on the newest spatial databases of energy sources [7]. For the work presented in this document, we have used the values of the Water Footprint, per energy source and stage, predicted in [7], and summarized in Table 1.

Energy source	Fuel supply [m^3/TJ]	Construction [m^3/TJ]	Operation [m^3/TJ]
Coal	134	1	437
Oil	73	1	175
Natural Gas	5	1	130
Nuclear	60	0.3	567
Hydropower	0	1	9113
Wind	0	1	0.2
Solar	0	90	27
Biodiesel	3279	1	0
Biodiesel	134345	1	0

Table 1: Average blue and green Water Footprint related to energy production in EU taken from [7]. Note that for the case of biodiesel the operation contribution to the WF is below the percent level (zero in our calculations) in comparison with the fuel supply phase [8].

Based on the procedures described in [6] and [9], the total WF of electricity, WF_{total}, is calculated by

$$WF_{total} = (WF_f + WF_c + WF_o) \times E \tag{2.1}$$

where WF_f is the average water footprint of the fuel supply per unit of electricity, WF_c is the average water footprint associated with the construction phase of the power plant expressed in units of electricity produced for the entire duration of the plant, and WF_o is the average water footprint in the operational phase per unit of electricity produced by fuel or renewable energy source (Table 1). E represents the annual production of electricity from fuel and renewable energy sources.

3 The Water Footprint in Spain

Following the methodology explained in section 2.1 we have performed a systematic study of the Water Footprint in Spain for the time period 1990 - 2018. Table 2 shows the different values of E in TJ, per year and energy source, used in this work. We obtained this data from a database provided by the EU Open Data Portal [10]. Regarding coil and biodiesel data, the database distinguish between contributions from brown and hard coal, and from biogas and solid biofuel. In our study (numbers in Table 2) we have added together both contributions in each case.

Year	Coal [TJ]	Oil [TJ]	Natural Gas [TJ]	Nuclear [TJ	Hydro [TJ]	Wind [TJ]	Solar [TJ]	Biodiesel [TJ]
1990	214113.6	30974.4	5432.4	195364.8	94248	36	36	1944
1991	211640.4	36561.6	4899.6	200080.8	101844	72	36	1944
1992	231199.2	51584.4	6159.6	200815.2	75348	360	36	2052
1993	224701.2	34358.4	4305.6	201600	92808	432	36	2088
1994	221626.8	37832.4	11624.4	199126.8	105048	648	72	2304
1995	238896	52642.8	14400	199638	88452	972	72	3636
1996	194198.4	50400	24361.2	201600	147132	1296	72	3924
1997	225615.6	50770.8	65426.4	199072.8	129600	2664	72	5256
1998	220644	62996.4	58363.2	212374.8	128916	4860	72	5508
1999	265006.8	88002	68608.8	211867.2	91584	9864	108	5832
2000	284731.2	81280.8	72640.8	223941.6	114516	17028	36	5400
2001	252961.2	88675.2	84088.8	229348.8	157896	24336	72	5868
2002	292240.8	102934.8	116589.6	226857.6	94572	33624	72	9288
2003	269002.8	86407.2	141724.8	222750	158040	43488	72	11484
2004	284792.4	85820.4	198000	228981.6	123984	56520	72	11952
2005	284594.4	86400	284439.6	207140.4	82872	76248	180	9540
2006	240249.6	85784.4	327600	216453.6	107388	83880	432	9972
2007	262054.8	66628.8	341276.4	198370.8	109872	99252	1872	10440
2008	175366.8	64807.2	434872.8	212302.8	94104	118620	9288	11700
2009	129265.2	69271.2	387885.6	189939.6	104976	137232	21816	12564
2010	91195.2	59623.2	341463.6	223200	163836	159372	25884	14472
2011	158331.6	52891.2	307828.8	207784.8	118476	154512	33840	16596
2012	198259.2	55155.6	263908.8	219600	86976	178092	43092	17928
2013	143798.4	49546.8	207129.6	204213.6	147780	200340	47160	20880
2014	157690.8	50835.6	170182.8	206298	154692	187236	49212	19512
2015	184924.8	62067.6	188992.8	205905.6	112932	177588	49896	20736
2016	131169.6	60915.6	190800	211078.8	143532	176076	49104	20484
2017	162446.4	56757.6	230533.2	208940.4	75852	176868	51840	21888
2018	134416.8	52192.8	208814.4	200757.6	132480	183240	45864	21240

Table 2: Annual amount of produced electricity in Spain, by energy source in TJ, taken form [10].

In this study we have differentiated between:

- Non Renewable energy sources: coil, oil, natural gas and nuclear.
- Renewable energy sources: hydropower, wind, solar and biodiesel.

3.1 Water Footprint of Non Renewable Energy Sources

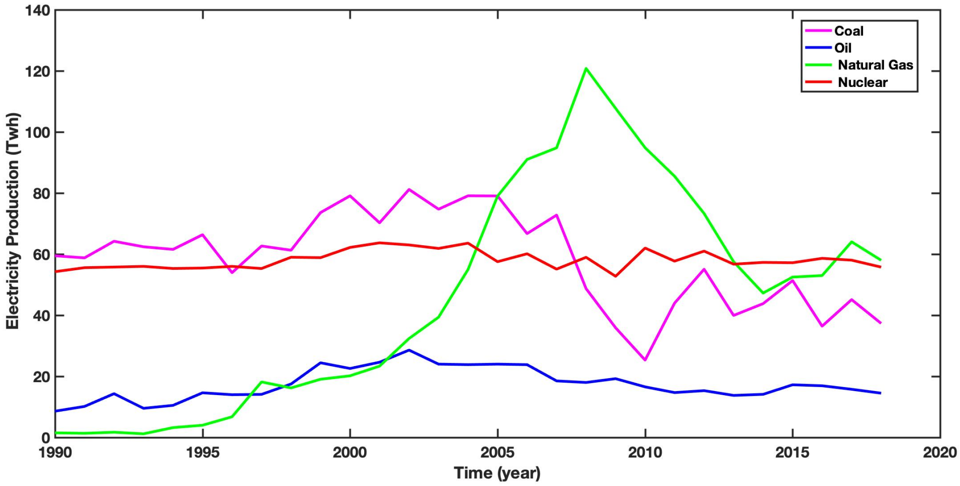

Figure 2: Electricity production of non renewable energy sources in Spain from 1990-2018.

Figure 2 shows the electricity production (in Twh) for non renewable energy sources in Spain for the time period of 1990 - 2018. From the figure, several features are easily observed. Nuclear and oil based electricity production remain almost constant in all the time period under study. On the contrary, for the case of coal and natural gas a dramatic change in trend is observed, with its inflection point in around the year 2005. Before that year, coal represents the maximum energy source in the electricity production, but after that year it suffers a dramatic drop (larger than a 50%) that lasts several years. On the contrary, the gas natural experiments the opposite behaviour, raising from the minimum weight in the electricity production, to represent the maximum contribution from 2005 (a big drop is observed also from 2009, but still being among the main contributions of its group). This anticorrelated trend between coil and natural gas can be understood by multiple reasons. One of them is the Spanish (and world) economical crisis suffered during that period and the fact that about 90% of the coal used in Spain is imported from other countries. Indeed, according to [11], in 2017, when Spain was more economically recovered, the trend in the coal importation increased by 28.5% in comparison with previous years.

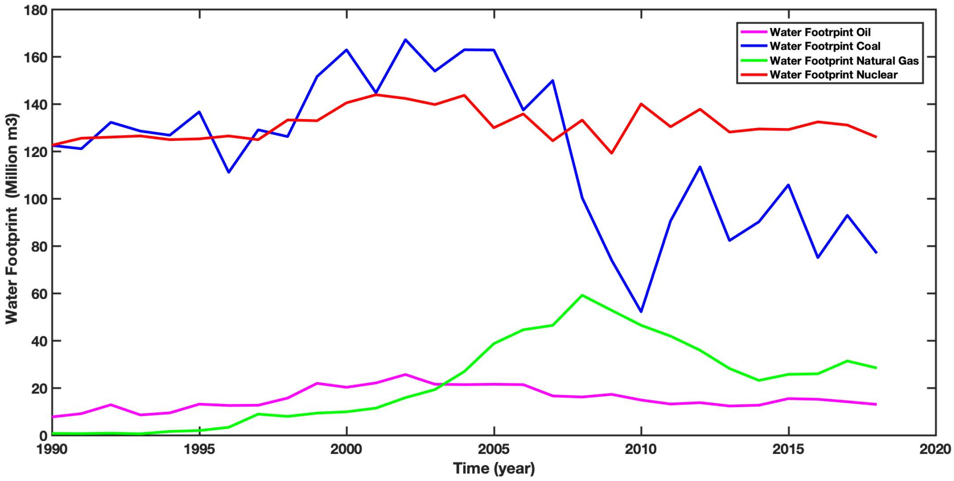

Figure 3: Estimated Water Footprint per non renewable energy sources in Spain for the time period 1990 - 2018. Calculations have been made using MatLab package [12], shown in Anexo I.

Another and very important reason for that decrease was the reduction of the greenhouse gas (GHG) emissions, for environmental purposes. Carbon dioxide (CO_2) makes up the vast majority of greenhouse gas emissions from the energy sector, but smaller amounts of methane (CH_4) and nitrous oxide (N_2O) are also emitted. These gases are released during the combustion of fossil fuels, such as coal, oil, and natural gas, on the phases of the production of electricity, but in very different amounts. For example, based on [13], the GHG emission from coil, has an average value of 0.3295 kg CO_2/kWh, which is a factor $\times 2$ larger than the contribution from natural gas, with a value of 0.182 kg CO_2/kWh. Following both i) the United Nations Framework Convention on Climate Change and its Kyoto Protocol, and later ii) the European Union legislation, Spain was forced to reduce its GHG emissions. In particular, for the period from 2008 to 2012, the first commitment period of the Kyoto Protocol, Spain had to limit the increase in its GHG up to 15% of the level of emissions in the reference years (1990-1995). Furthermore, from the period 2013 - 2020 during the European Energy and Climate Change Package, Spain and all EU member countries adopted the policy of the reduction of their GHG emission up to 20%. All this translated in favouring energy sources like natural gas with a small contribution to the GHG emissions in comparison with other preferred sources before, like coal (as seen in Figure 2).

Figure 3 shows the total WF (in million m^3) for the electricity production and energy sources showed in figure 2. As WF and E presents a linear dependency (see Equation 2.1), the trends in time described before (for E) are the same for the WF. But the important thing now are also the absolute values of the different components. The WF coming from nuclear and coal sources represent about a factor $\times 5$ larger than for the case of oil and natural gas. The case of natural gas is particularly relevant, in the sense that, while being nowadays the main (or among them) electricity producer in Spain (since 2005) its WF remains significantly small in comparison with its closer competitors. This last makes gas natural the better non renewable energy source in Spain in the balance electricity - WF generated.

3.2 Water Footprint of Renewable Energy Sources

Spain has a lot of potential to grow its electricity production through renewable energy sources, which in the other hand will include the benefit of reducing the emission of GHG. And in fact, in the last two decades renewable energy in Spain has become the fastest growing form of electricity production. Figure 4 shows the electricity production (in Twh) for renewable energy sources in Spain for the time period of 1990 - 2018. As we can observe, the electricity production through renewable energy sources has increased, in opposition to the case of non renewable sources (with the exception of natural gas) described in the previous section. This increase is particularly obvious for the case of wind production, becoming even larger than the contribution from hydro power plants (the dominant source from previous years). Nowadays, Spain is the leader in wind power generation being the country that has installed the most onshore capacity in the EU by 2019 [14] (15% of the total in Europe). In that year, wind power contributed 20.8% of the electricity consumed (in 2018 it was 19%), avoiding both 28 Mton CO_2 and imported 10.7 Mtoe (Mega tonne of oil equivalent) of fossil fuels.

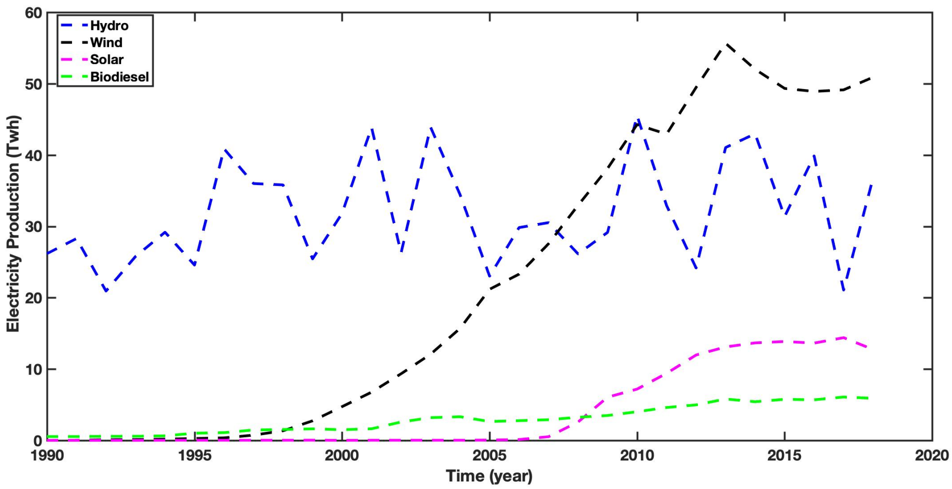

Figure 4: Electricity production by renewable energy sources in Spain from 1990-2018.

Since 2009, wind has been the technology that has contributed most to total renewable energy generation, as can be seen in Figure 4. This is due mainly to the fact that installed wind power capacity has grown year on year and because of its regularity in terms of annual generation. In fact, unlike hydro, whose dependence on meteorological conditions is extremely high, wind energy production is much more constant throughout the year, although it too has a certain degree of dependence on meteorological conditions.

Hydro together with wind are the leaders of the electricity production of renewable energy source. Meanwhile their WF are significantly different as shown in Figure 5. This is due to their extremely different, more than 4-orders of magnitude, WF during their operation phases (Table 1). For example, in 2010 the produced electricity by hydro and wind powers were very similar, 45.51 Twh and 44.27 Twh, while their WF values were 1493 million m^3 and 0.1912 million m^3 respectively ($\times$7800 different). And if we take into account all the time period under study, the average WF from wind and hydro are 0.0953 million m^3 and 1049.6 million m^3 respectively.

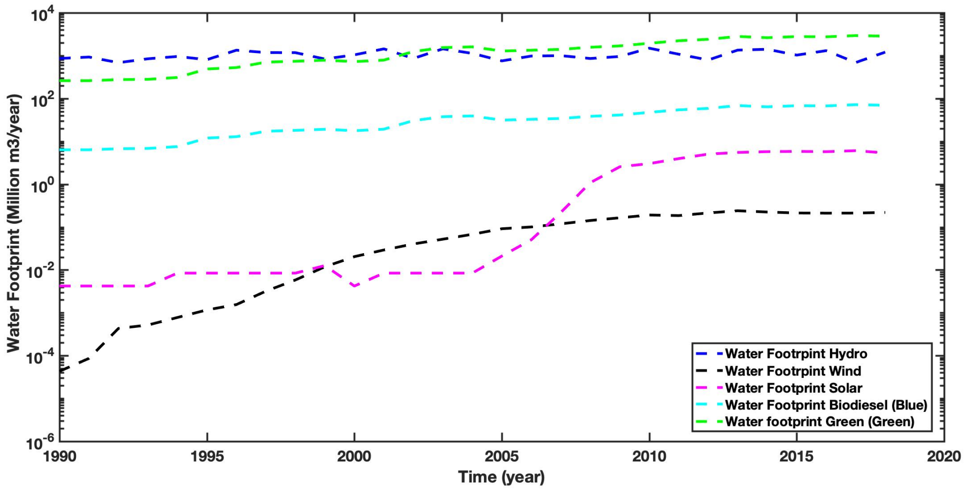

Figure 5: Calculated Water Footprint per renewable energy sources in Spain from 1990-2018.Note the y-axis logarithmic scale. Calculations have been made using MatLab package [12], shown in Anexo I.

The use of solar energy for electricity production has also grown in the last years, but it is still quite far from hydro and wind production. From the point of view of WF, solar energy source is also not competitive with wind. From Figures 4 and 5, we see how for an energy production about $\times 4$ smaller, the solar WF is more than one order of magnitude larger that the wind one.

The most extreme case in the E - WF balance is for the biodiesel energy source. In Figure 4 we see how electricity production by biodiesel presents a systematic increase with time. However, of all the renewable energy sources under study, it is the one that contributes least to electricity production in Spain. On the other hand, biodiesel presents the largest, by far, green and blue WF component (Table 1) from the production phase, due to irrigation, agricultural production and evapotranspiration. Its green component of WF is larger than the blue by about a factor $\times 41$. According to reference [15], WF of biodiesel can be in the range of $\times 70$-400 larger than the other primary energy carriers (excluding hydro), what is in agreement with our results showed in Figure 5 (note the log-scale in the y-axis). The product source of biomass and biogass, whose total sum is represented as the biodiesel term in Table 2, can be very diverse. Biomass is a shadow term for all the material flows that derive from the biosphere, such as food and feed crops, energy crops, and organic wastes, such as manure and crop residues. Biogas is a combustible gas that is generated in natural environments or in specific devices, by the biodegradation reactions of organic matter, through the action of microorganisms and other factors, in the anaerobic environment.

For example, the green and blue WF of biomass produced by maize in Brazil is 39.4 m^3/GJ (or 663.9 m^3/Tonne), by sugar beet in Netherland is 13.4 m^3/GJ (or 50.5 m^3/ Tonne) and in United States is 23.3 m^3 GJ (or 87.7 m^3/Tonne) [15]. For the case of a bio-gas like Bio-ethanol, the WF produced by maize in Brazil is 110 m^3/GJ (with 39% blue WF and 61% green WF), while the value for sugar beet in United States is 59 m^3/GJ (with 59% blue WF and 41% green WF) [16]. As illustrated with the numbers above, the total green and blue WF based on their primary product to produce biodiesel is very diverse. However, the database used for this work didn't have available that information, distinguishing only between whole blue and green WF contributions (as shown in Table 1).

Regarding Spain, in the last two decades the average WF of biodiesel source is 1454.2 million m^3, with more than 97% (1419.6 million m^3) coming form the green WF component and only about a 3% (34.6 million m^3) from the blue. In fact, only the green component of biodiesel WF is covering almost 50% of total WF demand in Spain. As a comparative example of blue and green WF in Spain, the amount of electricity generated from biodiesel integrated in the full time period under study is 85.1 Twh. A comparable amount of energy was generated from hydropower plants only within 2003 and 2010. The WF in both cases were 42173 million m^3 (green) and 2933 million m^3 (blue) respectively (almost a $\times 15$ factor difference).

3.3 Water Footprint per energy sources of some European countries

For completeness, we have include in our study the WF (blue and green) for some European Union (EU) countries in the time period 2008 - 2012. The selection of this particular period is motivated because those years are the only ones when complete and reliable data for the variables used in our work could be found [10]. Among all the EU countries we have selected a sample of six: Italy, Greece, Portugal, Sweden, Poland and France. Our selection has been driven trying to cover very different situations from the point of view of production electricity sources, e.g. from nuclear free to dominant contributions (see Figure 6).

3.3.1 Nuclear free

In Italy, the main electricity productions are through fossil fuel and hydro, representing the 62% and 17% respectively, for the time period that we are studying. Biodiesel and wind present very similar and smooth trends in time, while in the case of solar source, it is observed a rise in time of almost 2-orders of magnitude (see Figure 7). If we look to the WF, represented in Figure 8, the situation is very different: for our time period the average produced electricity by fossil fuel is 216.14 Twh with a WF of 83.35 million m^3, while the electricity production through hydro is 49.33 Twh, with 1061.879 million m^3 of WF. But are biodiesel together with hydro the electricity sources representing the dominant contribution to the total WF in Italy.

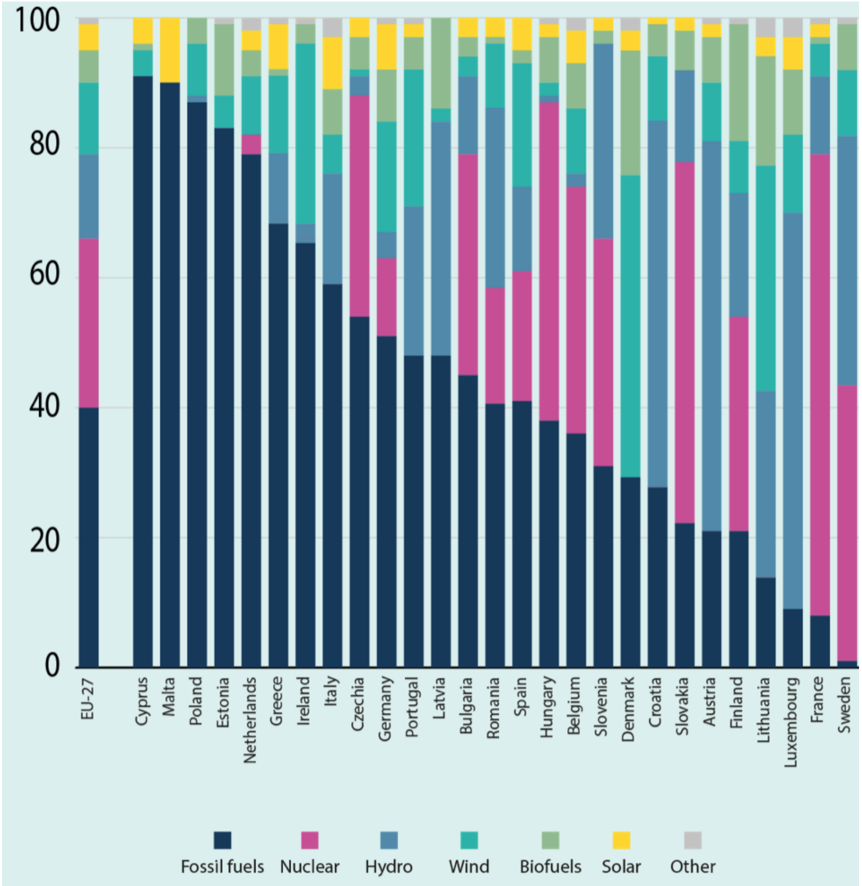

Figure 6: EU electricity production by energy source in 2018, from database *eurostat* [17].

Figure 7 also shows that in Greece (similarly than in Italy) the dominant electricity production source is the fossil fuel representing a 66% of total electricity demand. But in this case, renewable energy sources represent the remaining 34%. Among the renewable energy sources, hydro and wind are the leaders in the electricity production, as it was observed in Spain. The biodiesel evolution in time is almost flat, while in the case of solar energy, there is again an increase of more than two orders of magnitude for the period under study. In the context of WFs (Figure 8), the dominant contributions in Greece are hydro (49%) and biodiesel (28.5% of the total WF with 27.8% green and 0.7% blue), together with fossil fuel (22.4%).

In Portugal, the electricity production can be divided into fossil fuel and renewable sources each representing a 50% of the total contribution. Based on Figure 7, among the renewable energies, hydro and wind are the dominant sources with the second prevailing at the end of the period. As previously, biodiesel shows a stable behaviour in time while the solar contribution increases, but in the case of Portugal at a significantly lower rate than for Italy and Greece. In terms of WF (Figure 8) for the major electricity producers we have 21% for hydro, 2% for fossil fuel and 0.002% for wind. It is important to mention that biodiesel, while being relatively marginal in the whole electricity production in Portugal, it contributes with the 76% of total WF demand, making it the main WF holder in Portugal.

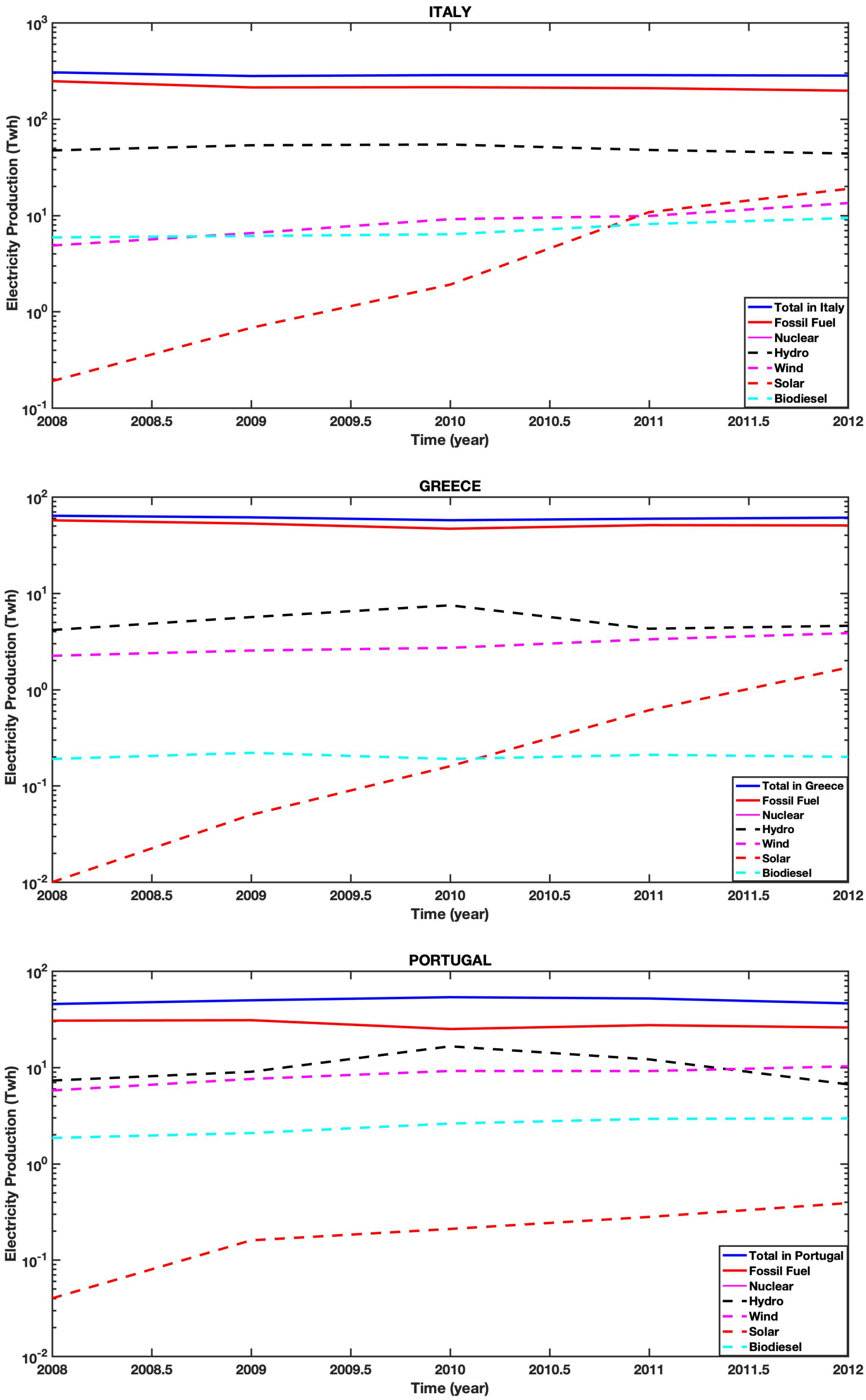

Figure 7: Electricity production per energy source for some EU countries nuclear energy free (note the y-axis logarithmic scale).

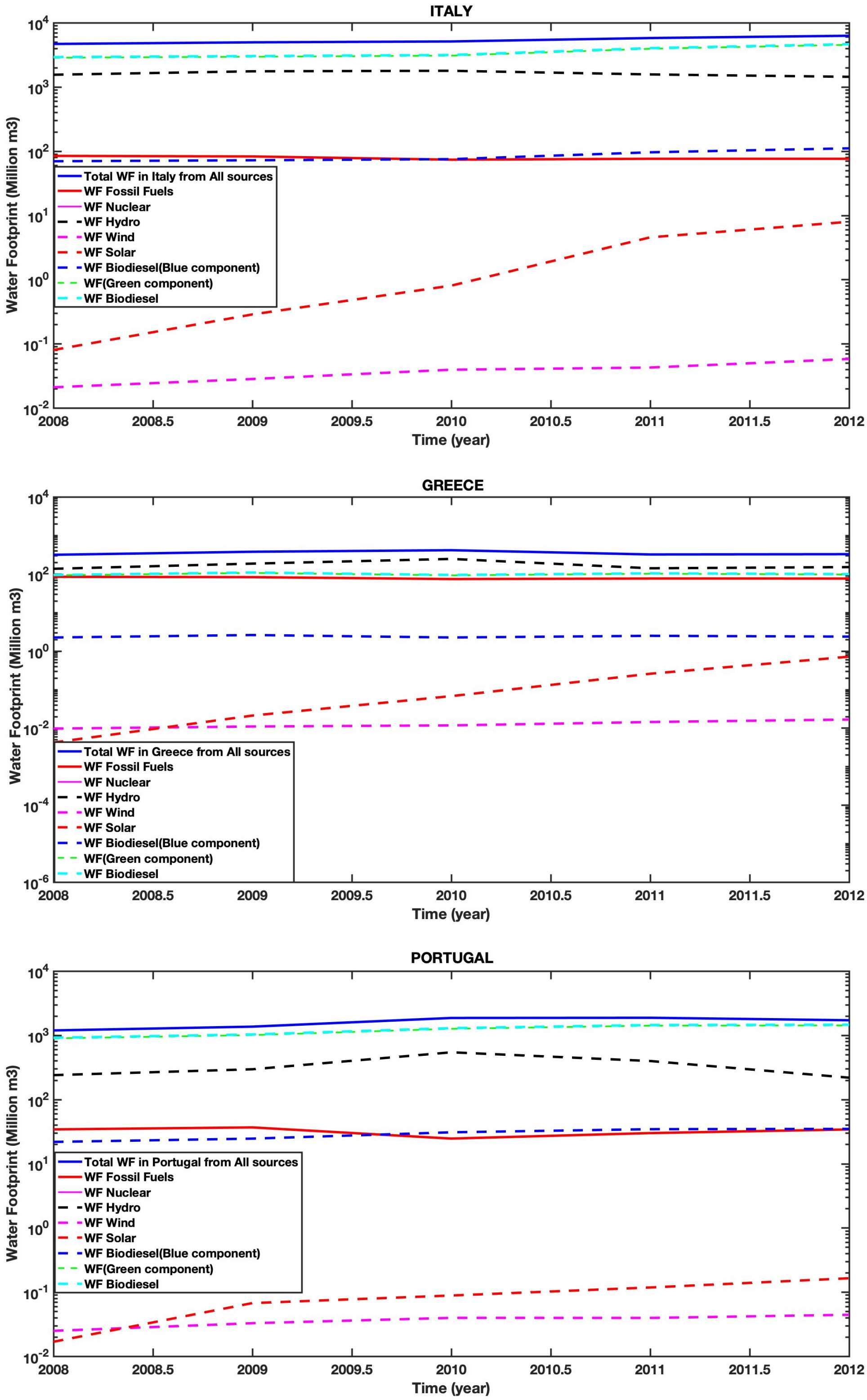

Figure 8: Water Footprint per energy source for some EU countries nuclear energy free (note the y-axis logarithmic scale).

For the three countries discussed above, the higher consume of blue and green WF is detected for biodiesel and hydro power sources. This places Italy at the forefront of WF consumption among the three.

As happens with Italy, Greece and Portugal, Poland is a nuclear free country. The main electricity producers in Poland, representing almost the 88% of the total generation, are burning fossil fuels like coal, natural gas and oil. Regarding renewable energy sources, that represent the 12% of total production, a smooth growing trend can be observed in the time period under study (Figure 9). This growth means a reduction in greenhouse gas emissions, in particular for carbon dioxide (CO_2), which is one of the main GHG released through the burning of fossil fuel. In recent decades the GHG in Poland has been reduced almost a factor $\times 1.5$, comparing with 1990 [18]. Although the leading electricity production is through fossil fuel, in terms of blue and green WF the situation is significantly different. Coal, which is the main source of fossil fuel for electricity production in Poland, represents 81% of total electricity demand, but only 8% of total WF for the 2008-2012 study period. Most of the WF is distributed among fossil fuel, hydropower and primarily biodiesel. Average electricity production using fossil fuel alone is 144.46 Twh, representing 286.21 million m^3 of WF, which corresponds to only 12.68% of total WF. The largest contribution to blue and green WF comes from biodiesel, with an average of 3254.14 million m^3, while its electricity production corresponds to only 4% of total demand (see Figure 10).

3.3.2 Nuclear dominant

In Sweden the major electricity demand is covered by nuclear and hydropower plants with 55% and 30% respectively (see Figures 6, 9), while the biodiesel together with wind are covering 15% of total electricity demand and only the 5% is covered by fossil fuel. Having most of the electricity production by nuclear and hydro power plants and a not negligible contribution by biodiesel, makes Sweden a country with one of the major WF in EU, as can be seen in Figure10. From the period 2008 - 2012 Sweden produced 645.7 Twh electricity by hydro and nuclear sources. This represents about the 85% of total electricity production. This represented the 94.5% of total blue WF demand and 30% of total WF. Biodiesel and fossil fuel while covering 7% and 5% of total electricity demand, represented the 70% and 0.03 % regarding the total WF. The last numbers clearly illustrate the incredibly large contribution to the WF by even a small fraction of biodiesel.

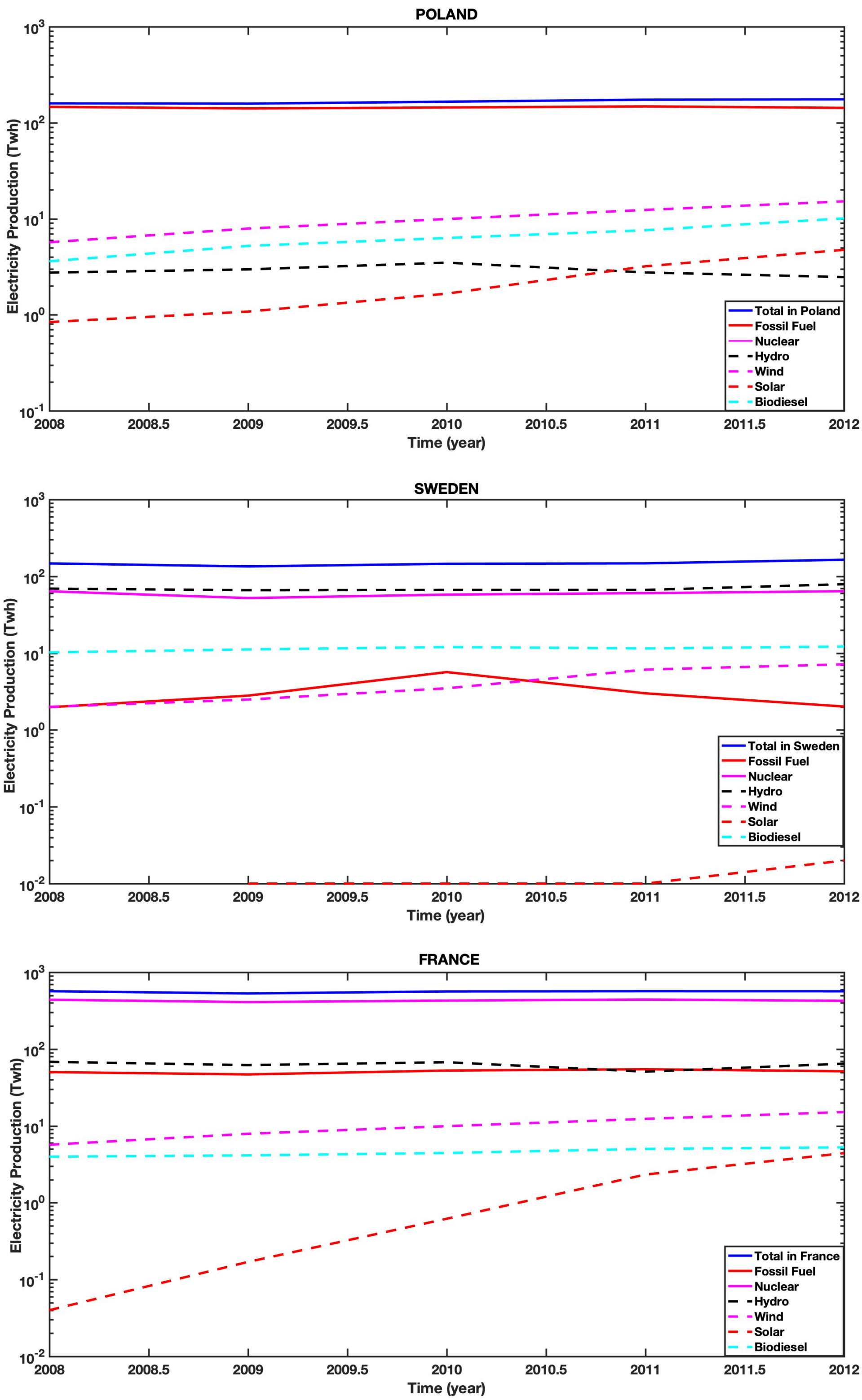

Figure 9: Electricity production per energy source of some EU countries (note the y-axis logarithmic scale).

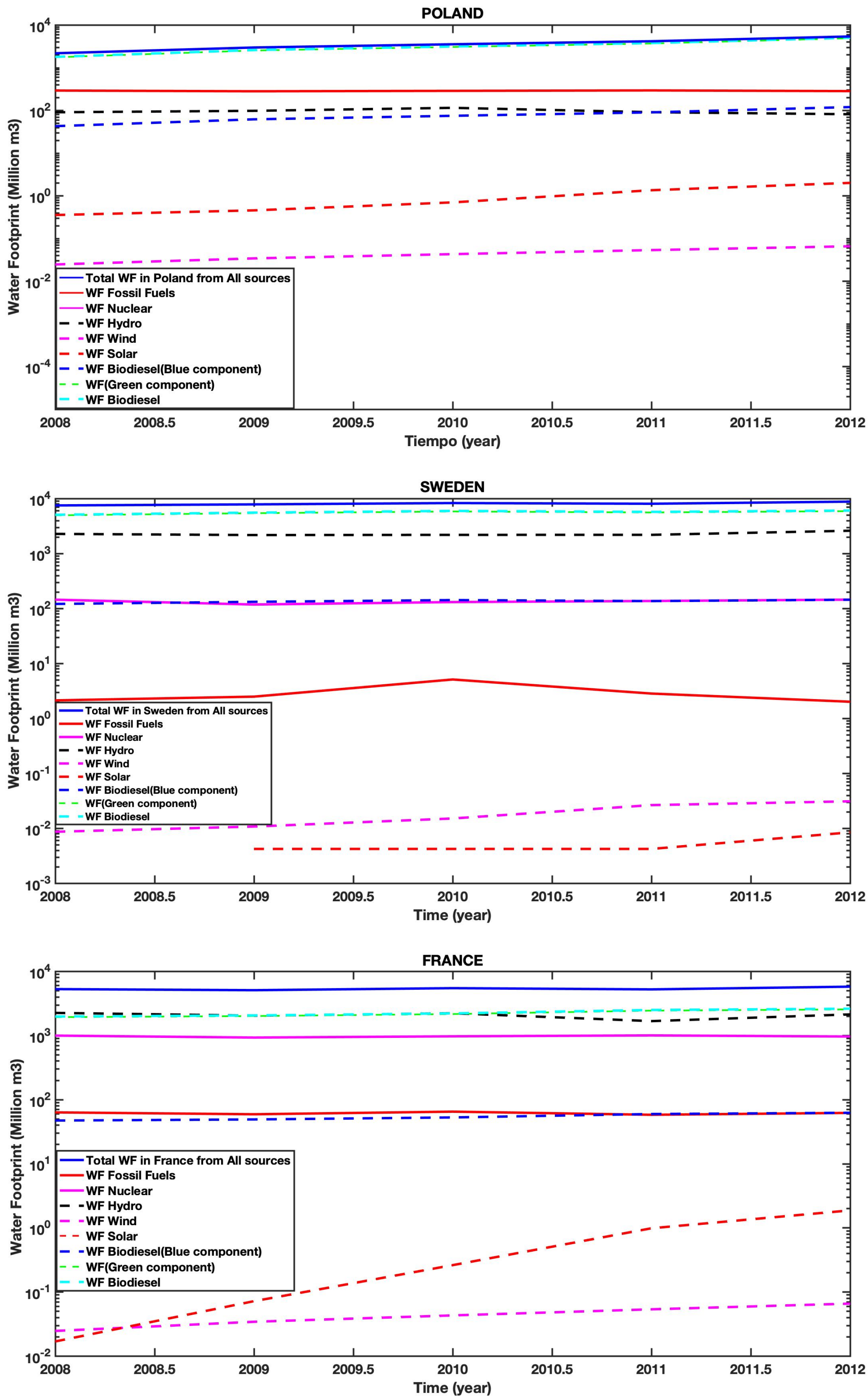

Figure 10: WF per energy source of some EU countries (note the y-axis logarithmic scale).

France is a leader in the production of electricity through nuclear energy, which covers almost 72% of its total demand (the largest in the EU). Second and third dominant electricity productions are generated through hydropower and fossil fuel plants. Renewable energy sources like wind, solar and biodiesel show positive growing values with time (Figure 9). As nuclear is the dominant source of electricity production and it has significant WF values during fuel supply chain, construction and operation phases, its contribution to the total WF in France will be important. In particular, in the period between 2008-2012 the average nuclear energy produced was 429.1 Twh with 969 million m^3, but this represents only the 18% of total WF. Wind and biodiesel are the second and third larger producers of electricity from renewable sources, but in terms of WF, they represent minimum and maximum cases (Figure 10). In fact, biodiesel together with hydro are the two sources that represent the largest contribution to total WF in France with about 40% weight each.

Country	Fossil Fuel	Nuclear	Hydro power	Wind	Solar	Biodiesel	Total
Sweden	2.9075	134.778	2279.076	0.0183	0.0042	5663.034	8079.817
Portugal	31.937	0	338.80	0.03623	0.09097	1229.715	1600.5792
Greece	78.589	0	171.664	0.01266	0.21228	100.081	350.5589
Poland	28.6214	0	94.756	0.04414	0.97128	3254.139	3378.531
France	61.236	969.032	2057.343	0.04410	0.63938	2265.21	5353.504
Italy	183.359	0	1618.79	0.03784	2.73274	3554.978	5359.897

Table 3: The average WF expressed in million m^3 for European countries for the period of 2008 - 2012 per energy source.

Table 3 summarises the WF results, per energy source, for the EU countries described in this section. From the table, it is very easy to see that Sweden and Greece represent the maximum and minimum extreme cases, respectively. This is a consequence of the huge (reduced) use of biodiesel in the electricity production by Sweden (Greece). However, according to the EU statistics database *eurostat* [19], Sweden is Europe's largest producer of renewable energy. As we have seen, this is absolutely not the case in terms of WF.

4 Water Footprint and Electricity production in the region of Andalusia

Using the database provided by the "Agencia Andaluza de la Energía" [20] we have carried out a systematic study about the WF in Andalusia region. The study includes the available information which comprises the time interval between 2000 and 2018 (the last two decades). This database distinguish only between renewable and non renewable energy sources, and the available information is shown in Figure 11.

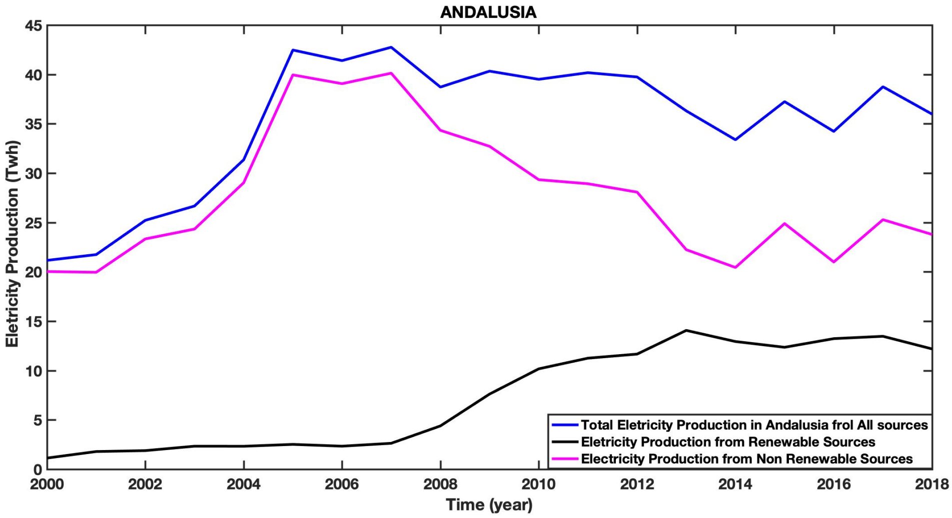

Figure 11: Electricity production in the region of Andalusia from renewable and non renewable energy sources in the time period 2000-2018 [20].

Andalusia region represents about the 13% of total electricity demand in Spain, and at the beginning of 21th century the production of electricity was mainly based on fossil fuel [21]. Around 2007 there was a drastic fall in the use of non renewable energies, resulting in a reduction of about a 40% at present. This behaviour was accompanied by a gradual increase in the use of renewable energies for the electricity production, as can be seen in Figure 11. The same trend was observed for the case of Spain, as we described in Section 3.1. Likewise, we relate this fall to the global economic crisis and also to the environmental restrictions imposed by Europe at that time. All this had a positive impact on the reduction of carbon dioxide emissions (CO_2) in the province of Andalusia. The sector that contributes most to CO_2 emissions in Andalusia is the production of electricity. As we saw earlier, in compliance with the Kyoto Protocol (1997), the European Union of 15 (EU-15) accepted the commitment to reduce its greenhouse gas emissions by 8% by the period 2008 - 2012. According to the annual publication of the "Consejería de Medio Ambiente y Ordenación del Territorio de la Junta de Andalucía" [22], CO_2 emissions in the period 2005 - 2014 have fallen from 32.35 million tonnes to 22.46 million tonnes, representing a drop of around 30%, which would be part of the drop of around 40% in electricity production from non-renewable sources mentioned above.

To calculate the total blue and green WF in Andalusia, as we have been doing in the previous sections, we would need the energy production information of each energy source. Due to the absence of this information (remember that for the case of Andalusia we only have available the energy generated by the total of renewable and total of non-renewable sources), we have had to use an approximation.

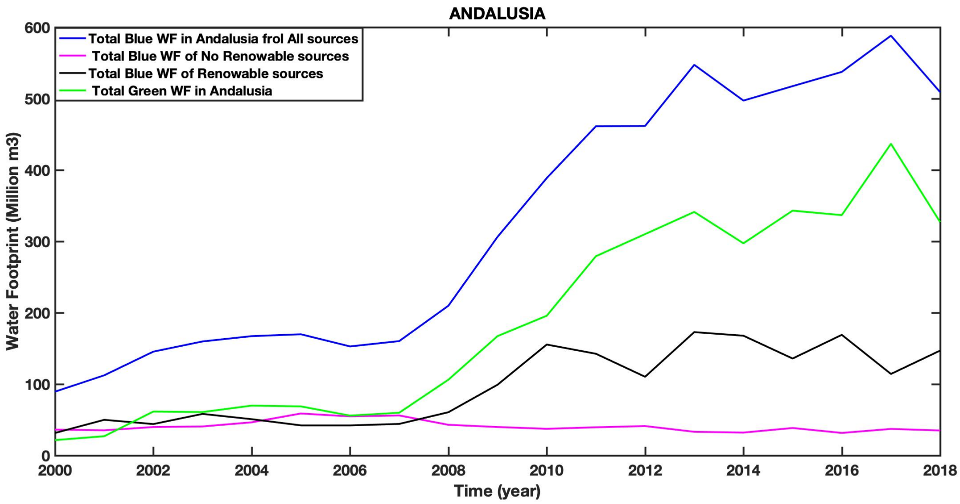

Figure 12: The blue and green WFs from the electricity production in the region of Andalusia.

In order to obtain the ”grouped” WF of renewable and non renewable energy sources in a realistic way, what we have assumed is that in Andalusia the relative weight of each of the renewable sources (i.e. hydro, wind, solar and biodiesel) and non-renewable sources (i.e. coal, oil, natural gas and nuclear) is the same as for the case of Spain in the same period of time. In that way, using the data by energy source in Spain (which are available and described in Section 3) we have calculated the relative weights, per energy source, shown in Table 4 that we will apply for the case of Andalusia. Thus, using the energies shown in Figure 11 we have been able to obtained the values of the WF for Andalusia, which are shown in Figure 12. Once more we see how renewable energies, while being subdominant in the production of electrical energy, end up being the main contribution to the total WF, basically driven by hydro and biodiesel sources. The average WF of non renewable energy sources in Andalusia region represents the 1.4%. On the other hand, WF from renewable sources in Andalusia represent the 8.6% of total WF demand in Spain.

As reported by [23], Andalusia is one of the leaders in the production of electricity through hydroelectric plants, which in turn, as we have seen, is one of the main producers of WF. According to our estimates of WF in Andalusia, hydroelectric plants account for 28% of total amount. On the other hand, one of the fastest growing forms of electricity production in the region has been biodiesel. According to the information provided by *Ecologistas en acción*, the region of Andalusia was the main one in the production of biodiesel in 2018, something that can be noticed in Figure 11, where we can see the increase of electricity production through renewable energy sources. This positive trend represents a rising development of green energy in Andalusia, but on the other hand it has its negative environmental effect in terms of water use, as it is increasing the total demand for WF. In a region like Andalusia, where the shortage of fresh water is a major problem, it becomes an issue particularly relevant. According to our calculations, electricity production through biodiesel in Andalusia would be covering 1% of the total electricity demand in the last two decades, while WF through this source would be 59% of the total WF in Andalusia.

Year	Coal [%]	Oil [%]	Natural Gas [%]	Nuclear [%]	Hydro [%]	Wind [%]	Solar [%]	Biodiesel [%]
2000	0.429	0.122	0.109	0.337	0.836	0.124	0.0002	0.039
2001	0.386	0.135	0.128	0.350	0.839	0.129	0.0003	0.031
2002	0.395	0.139	0.157	0.307	0.687	0.244	0.0005	0.067
2003	0.373	0.120	0.196	0.309	0.741	0.204	0.0003	0.053
2004	0.357	0.107	0.248	0.287	0.643	0.293	0.0003	0.062
2005	0.329	0.1	0.329	0.24	0.490	0.451	0.001	0.056
2006	0.276	0.098	0.376	0.248	0.532	0.415	0.002	0.049
2007	0.301	0.076	0.393	0.228	0.496	0.448	0.008	0.047
2008	0.197	0.073	0.490	0.239	0.402	0.507	0.039	0.050
2009	0.166	0.089	0.499	0.244	0.379	0.496	0.078	0.045
2010	0.127	0.083	0.477	0.311	0.450	0.438	0.071	0.039
2011	0.217	0.072	0.423	0.285	0.366	0.477	0.104	0.051
2012	0.269	0.074	0.358	0.297	0.266	0.546	0.132	0.054
2013	0.237	0.081	0.342	0.337	0.355	0.481	0.113	0.050
2014	0.269	0.086	0.290	0.352	0.376	0.455	0.119	0.047
2015	0.288	0.096	0.294	0.320	0.312	0.491	0.138	0.057
2016	0.220	0.102	0.321	0.355	0.368	0.452	0.126	0.052
2017	0.2466	0.086	0.349	0.317	0.232	0.541	0.158	0.067
2018	0.225	0.087	0.350	0.336	0.346	0.478	0.119	0.055

Table 4: Fraction of the different energy sources contributing to the electricity production in Andalusia in terms of renewable and non-renewable. These numbers have been estimated assuming Spain data for the same time period. Note: Calculations have been made using MatLab pack-age [11], shown in Anexo II.

5 Water Footprint of the energy system in WWTP in the province of Granada

5.1 WWTP available data in Granada

The research carried out in this section is based on information from ten WWTP provided by the *Diputacion Provincional de Granada*, all located in the province of Granada. Table 5 shows the provided information, based on their typology, capacity (in equivalent inhabitants), flow rate of treated water (in m^3) and electricity consummation (in Kwh).

However, the information provided from *Diputacion Provincional de Granada* was in some cases incomplete or completely missing for the Flow Rate and Electricity Consume. For the last cases, which occurs in four of the ten (*Benalúa de las Villas*, *Montillana*, *Galera* and *Castril*), we had to exclude those cases from our studies. For the former cases, which occurs in three of the ten (*Beas de Granada*, *Cañar* and *El Valle*), in order to be able to perform our analysis, we had to make some approximations.

Figure 13 shows the available Flow Rate of WWTP for *Beas de Granada* and *Cañar*. As can be seen, for these two municipalities, the information for several months of the year is missing. We have approximated the missing data by the average Flow Rate of the year calculated with the available months. Regarding the Electrical Consume of WWTP, for the cases of *Cañar* and *Órgiva*, some information about the electricity provider company was missing. For them, the available information was the price list and provider company (Endesa), but not the amount of used energy. To extract the Electricity Consume (showed in Table 5) we have used the available light rate prices from Endesa: 0.150378 Kwh/Eur and 0.162946 Kwh/Eur for *Cañar* (year 2015) and *Órgiva* (year 2018), respectively. An example for the former is shown in Figure 14. In the Left you can see an electricity bill from *El Valle* in 2015 showing the light rate price. In the Right, the 2015 pay-list for *Cañar* is shown.

Year	Municipality	Typology	Population Equivalent	Flow Rate [m^3]	Electricity Consume [Kwh]
2018	Beas de Granada	Trickling filter	1092	167331.15	67209
2018	Órgiva	Trickling filter	5460	344922.1	101975.5
2015	Benalúa de las Villas	Peat filter	1352	40049.19	Missing
2014	Montillana	Peat filter	1272	23860	Missing
2015	Cañar	Sequencing batch reactor(SBR)	249	117201.82	17964.7
2018	El Valle	Stahlermatic Plant	1130	107435	72445
2018	Galera	Extended aeration with submerged aerators	1119	Missing	55866
2018	Gorafe	Extended aeration with blowers and diffusers	526	8164.14	20337
2014	Zafarraya	BioDiscs	2146	142024	45770
2015	Castril	BioDiscs	2378	Missing	44119

Table 5: Summary of all available information from Waste Water Treatment Plant in the province of Granada. WWTPs from villages where part of the needed information was completely missing were excluded from the study (in red on the table).

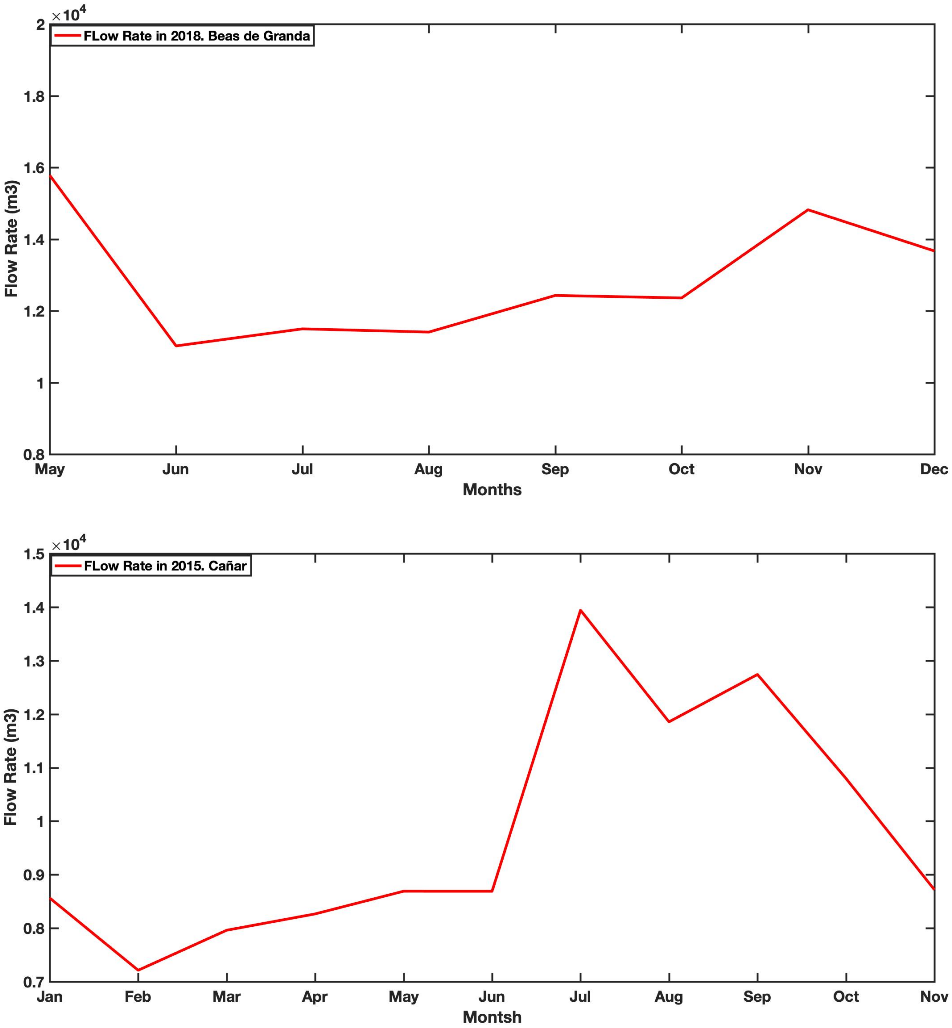

Figure 13: Top: Flow Rate of WWTP of Beas de Granada from May to December. Bottom: Flow Rate of WWTP of Cañar from January to November.

Figure 14: Example of electricity bill of WWTP for El Valle, and the WWTP price list of Cañar.

5.2 Typology and energy requirements of the WWTP in the province of Granada

WWTPs are electricity-intensive systems. In total, there are around 2533 WWTPs registered in Spain, where in the region of Andalusia alone there are 545, according to the publication in 2016 of the *Ministerio de Medioambiente de la Junta de Andalucía*, covering 21% of the total number of WWTPs registered in Spain [24]. These WWTPs cover the needs of a population of 7,118,859 people, which is 87% of the total undistributed population of Andalusia. Of the total of 545 WWTPs, only 50 of them are installed in the province of Granada. In this section we have studied the Water Footprint of the energy system of 6 WWTPs (of the 50) whose information has been provided by the *Diputacion Provincial De Granada*. Table 6 shows the information available after eliminating the incomplete cases described in Section 5.1.

The energy consumption in a WWTP varies according to the size of the plant, the pollutant load of the influent, the type of treatment and the technology used, so electricity consumption will vary from one to another. Table 6 contains the information about the sizes of the WWTPs in terms of their population equivalent, treatment methodology, annual flow rate and annual electricity consumption.

Year	Municipality	Typology	Population Equivalent	Flow Rate [m^3]	Electricity Consume [Kwh]
2018	Beas de Granada	Trickling filter	1092	167331.15	67209
2018	Órgiva	Trickling filter	5460	344922.1	101975.5
2015	Cañar	Sequencing batch reactor(SBR)	249	117201.82	17964.7
2018	El Valle	Stahlermatic Aerotor	1130	107435	72445
2018	Gorafe	Extended or Prolonged aeration	526	8164.14	20337
2014	Zafarraya	BioDiscs	2146	142024	45770

Table 6: Physical descriptions of the data available for the Wastewater Treatment Plants in Granada.

In *Beas de Granada* and *Órgiva* villages is used a WWTP typology of Trickling Filters for treating wastewater. Trickling filters (TFs) are used to remove organic matter from wastewater. It is an aerobic treatment system that utilises microorganisms attached to a medium to remove organic matter from wastewater. TFs are a secondary treatment after a primary setting process, after the waste water flew through septic tanks or pre treatment. In general it can consists of a fixed bed of rocks, coke, gravel, slag, polyurethane foam, sphagnum peat moss, over which sewage or other wastewater flows downward and causes a layer of microbial slime (biofilm) to grow, covering the bed of media. Aerobic conditions are maintained by splashing, diffusion, and either by forced-air flowing through the bed or natural convection of air if the filter medium is porous.

From the point of view of electricity consumption, this type of WWTP have high energy efficiency, comparable with activated sludge WWTP. Practically a pump and a hydraulic distributor are all the electro-mechanical equipment needed for a WWTP of this type, which is making this plants energy effective. This type of WWTP are suitable for small towns and have high effluent quality in terms of Biochemical Oxygen Demand (BOD) and suspended solids removal.

The WWTP installed in *Cañar* village is using Sequencing Batch Reactor(SBR) technology for treating the water. The SBR is an optimized variant of conventional activated sludge technology. It is based on the use of a single reactor that operates in a sequential batch mode. The SBR system consists of at least four cyclic processes: filling, aeration, anoxic stage, decantation and emptying of both effluent and sludge. One of the main advantages of this type of WWTP is the compact installed size of plant and low costs. They are very suitable for small town with relatively small population. The SBR does not require high electricity resources, even though their system require the aeration stage. This is directly related with the treatment method, which requires a short aeration and rest phases alternate in a controlled cleaning process. The BOD removal efficiency is generally 85 to 90%.

In *El Valle* the installed WWTP is working with the Stahlermatic-Aerotor (STM-Aeromotor) technology of treating wastewater [24]. The STM-Aeromotor is designed as a rotor equipped with pipes created by media-discs. As soon as a pipe of the rotor emerges above water level during rotation, the mixed liquor inside the pipes flows out. By this it is firstly aerated at the spillway. The pipe will then be filled with atmospheric air necessary oxygen for the fixed film dissolves on the wet surfaces of the media discs with every rotation, the STM-Aerotor captures atmospheric air, draws it down into mixed liquor in a steel or concrete basin, and slowly releases it as course bubble aeration. During the rotation, additional cascade aeration elevates the dissolved oxygen in the upper layer of the basin. The combination of the slow rotation of the STM-Aerotor, the intense air release, and the addition of a peripheral mixing paddle ensure a thoroughly mixed system. In addition, the STM-Aerotor includes a large surface area for fixed film growth (biofilm). The interior and exterior of the special polypropylene discs provide the perfect environment for a variety of attached growth organisms. By rotating the rotor by a motor above water level, surface air is captured by the special design of the fixed film media and consequently the microorganisms in the basin are supplied with oxygen. This way to remove Biological Nutrient (BNR) requires relatively high electricity demand, which is related with the slowly rotated motor. Although this system does not require specific blowers or diffusers for the aeration system, the electricity demand required is significantly high.

In *Gorafe* the WWTP is working with extended or prolonged aeration system. The extended aeration process is one modification of the activated sludge process which provides biological treatment for the removal of biodegradable organic wastes under aerobic conditions. Air may be supplied by mechanical or diffused aeration to provide the oxygen required to sustain the aerobic biological process. Diffused air is introduced into the aeration tank, this provides the proper environment for the development of aerobic bacteria. These bacteria thrive on the materials contained in the wastewater. Mixing must be provided by aeration or mechanical means to maintain the microbial organisms in contact with the dissolved organics, which depends on the methodology will increase or decrease the energy demand of WWTP. In the extended aeration process, the raw sewage goes straight to the aeration tank for treatment. The whole process is aerobic, where there is no need of Primary Settling Tank. Extended aeration package plants consist of a steel tank that is compartmentalized into flow equalization, aeration, clarification, disinfection, and aerated sludge holding/digestion segments. These extended aeration plants are providing excellent Biochemical Oxygen Demand and Total Suspended Solids (TSS) removal efficiency. Extended aeration is preferred for relatively small waste loads. In the case of *Gorafe* the annual flow rate is 8164.14 m^3, the minimum value on Table 6.

In the village of *Zafarraya* the installed methodology for the treatment of wastewater is through Bio-disk. Bio-disk is a natural biological process for the treatment of wastewater based on the principle of rotating biological contactors (RBC's). This process has many inherent operating characteristics that make it suitable for the treatment of domestic or commercial wastewater. The discs remain semi-submerged in the water so that when they rotate they put the biofilm in contact with the water and the air in an alternative way. Biofilms, which are biological growths of biomass that become attached to the bio-discs, digest the organic materials in the wastewater. The aeration system does not require special blowers, which makes this waste water treatment system energy efficient. The aeration is provided by the rotating action, which exposes the bio-discs to the air after contact with wastewater. The threaded effluent then flows to a final settlement tank where dead bacterias and small particles settle to the bottom. The cleaned effluent then discharges through the outlet. The discs themselves treat the sewage effluent after it has passed through a Primary Settlement Tank. The primary settlements tank settles the solids which form of a sludge in the bottom of the tank. The rotation is achieved via a motor, which is manly required machine of electricity.

5.3 Water Footprint and Used Fresh Water of WWTP in the province of Granada

According to the physical description information of the WWTPs showed in Table 6, the ratio of treated water (m^3) to consumed electricity (Kwh), which is known as ”ratio of energy consumption”, was calculated and values are shown in Table 7.

Year	Municipality	Ratio(Kwh/m^3)
2018	Beas de Granada	0.4016
2018	Órgiva	0.2956
2015	Cañar	0.15097
2018	El Valle	0.6743
2018	Gorafe	2.491
2014	Zafarraya	0.322

Table 7: Amount of Kwh of consumed electricity per 1 m^3 of treated water for the WWTPs under study in Granada ("Ratio" in the table).

The energy requirements for WWTPs depend on the size and type of the treatment process employed, which typically requires about 60-70% of the total energy demand in the plant. As shown in Table 7 the highest ratio of electrical energy consumption per volume of treated water is detected in the WWTP installed in the village of *Gorafe*, where the treatment process is carried out by extended or prolonged aeration which, as we have described above, is a modification of the activated sludge process. The value of this ratio calculated from the data supplied by the *Diputación Provincial de Granada* is 2.491 Kwh/m^3. This value is quite similar to the value obtained in [25] where 17 activated sludge WWTPs were studied in Greece and reported a value in the range 0.128 – 2.280 Kwh/m^3.

The smaller WWTPs with significantly smaller treated flow rate per day (m^3/day) are characterised by high energy consumption compared to relatively larger-scale WWTPs. Although small-scale wastewater treatment plants have a simplified configuration in wastewater and sludge handling processes, the unit energy consumption is higher than that of larger wastewater treatment plants due to less frequent optimisations. Multiple studies showing this behavior are described in [26]. The same trend has been observed for the WWTPs in the province of Granada that we have analyzed. In Table 8 we can see how energy consumption decreases substantially when the scale of the plant (flow rate per day) increases. For example, in the two extreme cases we would have daily flows of 24.9 m^3/day and 948.9 m^3/day which would correspond with energy consumptions of 2.49 Kwh/m^3 and 0.29 Kwh/m^3 for *Gorafe* and *Órgiva*, respectively.

Municipality	Ratio (Kwh/m^3)	Flow Rate (m^3/day)
Beas de Granada	0.4016	457.41
Órgiva	0.2956	948.9
Cañar	0.15097	328.6
El Valle	0.6743	328.9
Gorafe	2.491	24.9
Zafarraya	0.322	463.99

Table 8: The unit of energy consumption of the WWTPs with respect to the flow rate.

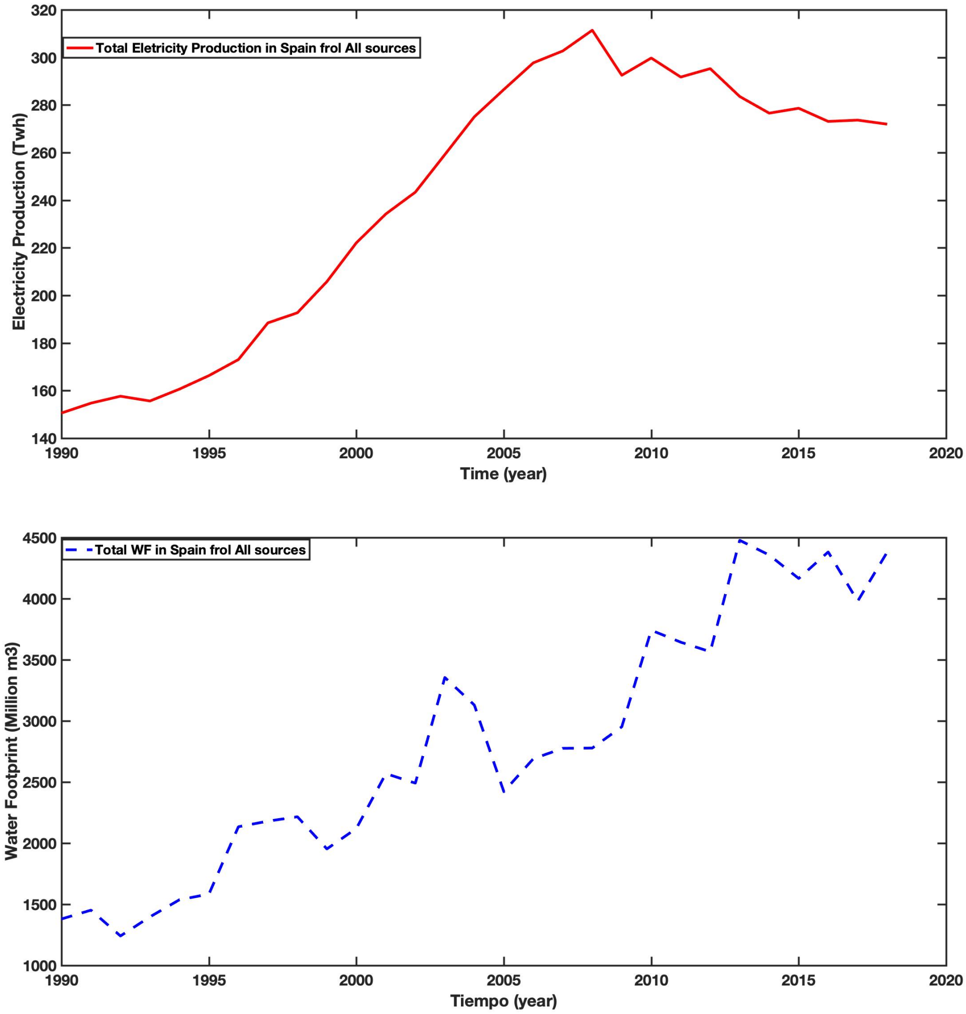

Figure 15: Total electricity production (Top) and total WF (Bottom) in Spain from the period 1990 - 2018.

The water-energy nexus is the relationship between how much water is used for energy production, and how much energy is used to collect, clean, move, store, and dispose of water (and wastewater). In fact, the concepts of Water Footprint and Used Fresh Water, although interesting in themselves, were invented to clarify this nexus.

Total electricity generation over the last three decades in Spain has increased by almost a factor ×2. Taking into account all renewable and non-renewable energy sources together, its value has risen from 150.6 TWh to 271.9 TWh over that period (Figure 15-Top). In Section 3 we also calculated the blue and green WF corresponding to this electricity generation. As we know, both magnitudes (produced energy and water footprint) present a linear relationship, so that the WF has experienced its corresponding growth, as shown in Figure 15-Bottom. The large fluctuations with time observed for the total WF is the results of the variation with time of the relative weights of the different energy sources (see Table 4), that are associated with quite different WFs (see Table 1).

Finally, to answer our initial question *"How much fresh water do we use to treat the water?"*, the new term Used Fresh Water (UFW) was introduced. It represents the amount of fresh water that was used in the energy production phase (described by the WF calculations) and expressed in m^3/Kwh, related to the total energy consumed per volume of treated water in WWTP expressed in Kwh/m^3 (described by the unit of energy consumption).

We have obtained the amount of fresh water used in the energy production in Spain by computing the ratio between the data shown in the bottom and top panels of Figure 15. Results are shown in Figure 16. The ratio of the average blue and green WF (m^3) per unit of generated electricity is 0.01139 m^3/Kwh (or 11.39 L/Kwh), showing an increase of about a factor $\times 1.5$ from 1990 until 2018, varying from 9 L/Kwh to 16 L/Kwh respectively.

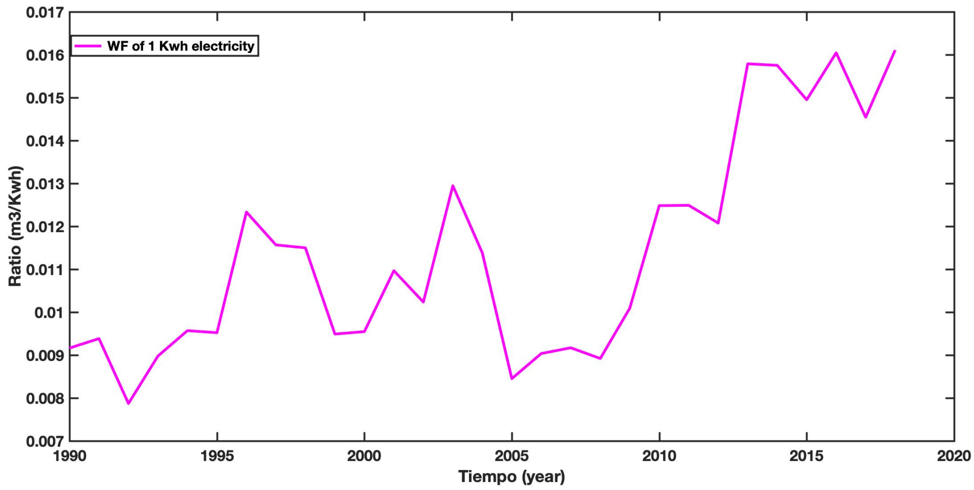

Figure 16: The ratio of blue and green WF per total produced electricity in Spain during the period 1990- 2018

To calculate the UFW values for the different WWTPs studied in the Granada region I have used the unit of energy consumed described in Table 8 together with the values of WF per unit of energy generated shown in Figure 16 (for the relevant years where data for the 6 WWTPs is available). The obtained results are shown in Table 9. Each number on the table, expressed in m^3/m^3, represents the amount of fresh water (including both blue and green WF) that was needed to treat 1 m^3 of waste water in the WWTPs. From the values in the table, which are all at the percent level and below, it can be concluded that the waste of fresh water compared to the volume of treated water is negligible.

Year	Municipality	Ratio(m^3/m^3)
2018	Beas de Granada	0.0065
2018	Órgiva	0.0048
2015	Cañar	0.0022
2018	El Valle	0.0109
2018	Gorafe	0.0401
2014	Zafarraya	0.0051

Table 9: Ratio of Used Fresh Water(UFW) expressed in m^3 of fresh water (WF) per m^3 of treated water for the 6 WWTPs under study in the province of Granada.

6 Summary and conclusions

References

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7 Anexo I

```
% % % WATER FOOTPRINT NON RENOVABLE SOURCES % % %

% %%%%%%%%%%%%%%% ITALIAN METHOD %%%%%%%

% % 1. ______WF_Total_Coal _____ % %

Time = [1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
    ↪ 2003 2004 ...
    2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018];
% WF_Total_Coal = WF_e_f_Coal*FEE_Coal + (WF_Construcion_Coal +
    ↪ WF_Operation_Coal)*E_Coal;
% E_Coal unit is TWh:
E_Coal_hard = [42.63 42.69 48.22 46.54 47.42 52.36 42.05 51.07 51.29 62.50
    ↪  67.61 59.84 69.50 64.60 68.59 69.03 58.24 64.42 45.38 34.02 24.05
    ↪ 39.98 52.05 37.70 40.87 48.13 34.59 42.56 35.60]; % TWH
E_Coal_brown = [16.846 16.099 16.002 15.877 14.143 14 11.894 11.601 10
    ↪ 11.113 11.482 10.427 11.678 10.123 10.519 10.024 8.496 8.373 3.333
    ↪ 1.887 1.282 4.001 3.022 2.244 2.933 3.238 1.846 2.564 1.738]; %TWH
E_Coal = E_Coal_hard+E_Coal_brown; % TWh/Year
WF_Fuel_Sypply_Coal = 134; % m3/TJ from EU Webpage
WF_Construcion_Coal = 1; % m3/TJ from EU Webpage
WF_Operation_Coal = 437; % m3/TJ
E_Coal_TJ = E_Coal*3600; % To convert Twh to TJ

format long
WF_Total_Coal_IT = ((WF_Fuel_Sypply_Coal + WF_Construcion_Coal +
    ↪ WF_Operation_Coal)*E_Coal_TJ)/1000000; % Million m3/year
```

```
figure(1);
plot(Time, WF_Total_Coal_IT,'-b');
xlabel('Tiempo (year)'); ylabel('Water Footprint million (m3/year)');
legend('WF Coal Source');
%


% % 2. ______WF_Total_Oil _____ % %

E_Petrol = [8.604 10.156 14.329 9.544 10.509 14.623 14 14.103 17.499
    ↪ 24.445 22.578 24.632 28.593 24.002 23.839 24 23.829 18.508 18.002
    ↪ 19.242 16.562 14.692 15.321 13.763 14.121 17.241 16.921 15.766
    ↪ 14.498]; %TWh
E_Fuel = E_Petrol; % TWh/Year
WF_Fuel_Supply_Oil = 73; % m3/TJ from EU Webpage
WF_Construcion_Fuel = 1; % m3/TJ from EU Webpage
WF_Operation_Fuel = 175; % m3/TJ
E_Fuel_TJ = E_Fuel*3600; % TJ

WF_Total_Fuel_IT = ((WF_Fuel_Supply_Oil + WF_Construcion_Fuel +
    ↪ WF_Operation_Fuel)*E_Fuel_TJ)/1000000; % Million m3/year
figure(2);
plot(Time, WF_Total_Fuel_IT,'-r');
xlabel('Tiempo (year)'); ylabel('Water Footprint million (m3/year)');
legend('WF Oil Source ');

% % 3. ______WF_Total_Natural_Gas _____ % %

E_Natural_Gas = [1.509 1.361 1.711 1.196 3.229 4 6.767 18.174 16.212
    ↪ 19.058 20.178 23.358 32.386 39.368 55 ...
    79.011 91 94.799 120.798 107.746 94.851 85.508 73.308 57.536 47.273
        ↪ 52.498 53 64.037 58.004 ]; %TWh
WF_Fuel_Supply_Natural_Gas = 5; % m3/TJ from EU Webpage
WF_Construcion_Natural_Gas = 1; % m3/TJ from EU Webpage
WF_Operation_Natural_Gas = 130; % m3/TJ
E_Natural_Gas_TJ = E_Natural_Gas*3600; % TJ

WF_Total_Natural_Gas_IT = ((WF_Fuel_Supply_Natural_Gas +
    ↪ WF_Construcion_Natural_Gas + WF_Operation_Natural_Gas)*
    ↪ E_Natural_Gas_TJ)/1000000; % Million m3/year
figure(3);
plot(Time, WF_Total_Natural_Gas_IT ,'-g')
xlabel('Tiempo (year)'); ylabel('Water Footprint million (m3/year)');
legend('WF Natural Gas source ');


% % 4. ______WF_Total_Nuclear _____ % %
```

```
E_Nuclear =[54.268 55.578 55.782 56 55.313 55.455 56 55.298 58.993 58.852
    ↪ 62.206 63.708 63.016 61.875 63.606 57.539 ...
60.126 55.103 58.973 52.761 62 57.718 61 56.726 57.305 57.196 58.633
    ↪ 58.039 55.766]; % TWh/Year
WF_Fuel_Supply_Nuclear = 60; % m3/TJ from EU Webpage
WF_Construcion_Nuclear = 0.3; % m3/TJ from EU Webpage
WF_Operation_Nuclear = 567; % m3/TJ
E_Nuclear_TJ = E_Nuclear*3600; % TJ
format long

WF_Total_Nuclear_IT = ((WF_Fuel_Supply_Nuclear + WF_Construcion_Nuclear +
    ↪ WF_Operation_Nuclear )*E_Nuclear_TJ)/1000000; % Million m3/year
figure(4);
plot(Time, WF_Total_Nuclear_IT,'-k');
xlabel('Tiempo (year)'); ylabel('Water Footprint Million (m3/year)');
legend(' WF Nuclear Source ');

figure(5)
plot(Time,WF_Total_Fuel_IT,'-m',Time,WF_Total_Coal_IT, '-b', Time,
    ↪ WF_Total_Natural_Gas_IT,'-g',Time, WF_Total_Nuclear_IT, '-r');
xlabel('Time (year)'); ylabel('Water Footprint Million (m3/year)');
legend('Water Footrpint Oil','Water Footrpint Coal','Water Footprint
    ↪ Natural Gas','Water Footprint Nuclear');

% Time = (Time)'; WF_Total_Fuel = (WF_Total_Fuel)';WF_Total_Nuclear = (
    ↪ WF_Total_Nuclear)';WF_Total_Coal = (WF_Total_Coal)';
    ↪ WF_Total_Natural_Gas = (WF_Total_Natural_Gas)';% transformar
    ↪ vectores filas en vectores columnas
% Years = [Time]; WF_Total_Fuel = [WF_Total_Fuel]; WF_Total_Nuclear = [
    ↪ WF_Total_Nuclear];WF_Total_Coal = [WF_Total_Coal];
    ↪ WF_Total_Natural_Gas = [WF_Total_Natural_Gas];
% table(Years, WF_Total_Fuel,WF_Total_Nuclear,WF_Total_Coal,
    ↪ WF_Total_Natural_Gas)
%
% Time = (Time)'; F_Coal = (F_Coal)';F_Fuel = (F_Fuel)';F_Natural_Gas = (
    ↪ F_Natural_Gas)'; F_Nuclear = (F_Nuclear)';% transformar vectores
    ↪ filas en vectores columnas
% Years = [Time]; F_Coal = [F_Coal]; F_Fuel = [F_Fuel];F_Natural_Gas = [
    ↪ F_Natural_Gas]; F_Nuclear = [F_Nuclear];
% table(Years, F_Coal,F_Fuel,F_Natural_Gas,F_Nuclear)
%
% Time = (Time)'; E_Coal = (E_Coal)';E_Fuel = (E_Fuel)';E_Natural_Gas = (
    ↪ E_Natural_Gas)'; E_Nuclear = (E_Nuclear)';% transformar vectores
    ↪ filas en vectores columnas
% Years = [Time]; E_Coal = [E_Coal]; E_Fuel = [E_Fuel];E_Natural_Gas = [
    ↪ E_Natural_Gas]; E_Nuclear = [E_Nuclear];
```

```
% table(Years, E_Coal,E_Fuel,E_Natural_Gas,E_Nuclear)
%
%
figure(6)
plot(Time,E_Coal,'-m',Time,E_Fuel, '-b', Time, E_Natural_Gas,'-g',Time,
    ↪ E_Nuclear, '-r');
xlabel('Time (year)'); ylabel(' Electricity Production (Twh)');
legend('Coal','Oil',' Natural Gas',' Nuclear');


% ____________________________________________________________ %

% % % WATER FOOTPRINT RENOVABLE SOURCES % % %

% % 1. ____ WF_Hydro ___ % %

E_Hydro_TWh = [26.18 28.29 20.93 25.78 29.18 24.57 40.87 36.00 35.81 25.44
    ↪  31.81 43.86 26.27 43.90 34.44 23.02 29.83 ...
30.52 26.14 29.16 45.51 32.91 24.16 41.05 42.97 31.37 39.87 21.07 36.80];
    ↪ % TWh
E_Hydro_TJ = E_Hydro_TWh*3600; % To convert Twh/Year to TJ/Year
WF_e_f_Hydro = 0; % m3/TJ
WF_Construcion_Hydro = 1; % m3/TJ from EU Webpage
WF_Operation_Hydro = 9113; % m3/TJ
format long
WF_Total_Hydro =((WF_e_f_Hydro + WF_Construcion_Hydro + WF_Operation_Hydro
    ↪ )*E_Hydro_TJ)/1000000; % m3/year

% % 2. ____ WF_Wind ___ % %

E_Wind_TWh = [0.01 0.02 0.10 0.12 0.18 0.27 0.36 0.74 1.35 2.74 4.73 6.76
    ↪ 9.34 12.08 15.70 ...
21.18 23.30 27.57 32.95 38.12 44.27 42.92 49.47 55.65 52.01 49.33 48.91
    ↪ 49.13 50.90]; % TWh
E_Wind_TJ = E_Wind_TWh*3600; % To convert Twh/Year to TJ/Year
WF_e_f_Wind = 0; % m3/TJ
WF_Construcion_Wind = 1; % m3/TJ from EU Webpage
WF_Operation_Wind = 0.2; % m3/TJ
format long
WF_Total_Wind =((WF_e_f_Wind + WF_Construcion_Wind + WF_Operation_Wind)*
    ↪ E_Wind_TJ)/1000000; % Million m3/year

% % 3. ____ WF_Solar ___ % %

E_Solar_TWh = [ 0.01 0.01 0.01 0.01 0.02 0.02 0.02 0.02 0.02 0.03 0.01
    ↪ 0.02 0.02 0.02 0.02...
```

```
0.05 0.12 0.52 2.58 6.06 7.19 9.40 11.97 13.10 13.67 13.86 13.64 14.40
    ↪ 12.74]; % TWh
E_Solar_TJ = E_Solar_TWh*3600; % To convert Twh/Year to TJ/Year
WF_e_f_Solar = 0; % m3/TJ
WF_Construcion_Solar = 90; % m3/TJ from the Reference Article.
WF_Operation_Solar = 27; % m3/TJ
format long
WF_Total_Solar =((WF_e_f_Solar + WF_Construcion_Solar + WF_Operation_Solar
    ↪ )*E_Solar_TJ)/1000000; % Million m3/year


% 4. ____ WF_Biodiesel ___ % %

E_Biodiesel_Solid = [0.54 0.54 0.56 0.57 0.61 0.86 0.94 1.31 1.37 1.43
    ↪ 1.18 1.30 ...
    2.11 2.43 2.50 2.03 2.17 2.29 2.67 2.96 3.17 3.81 4.11 4.83 4.51 4.78
        ↪ 4.78 5.14 4.98]; % Twh
E_Biogas = [0.00 0.00 0.01 0.01 0.03 0.15 0.15 0.15 0.16 0.19 0.32 0.33
    ↪ 0.47 0.76 0.82 0.62 0.60...
    0.61 0.58 0.53 0.85 0.80 0.87 0.97 0.91 0.98 0.91 0.94 0.92]; % Twh
E_Biodiesel = E_Biodiesel_Solid + E_Biogas; % TWh/Year
WF_e_f_Biodiesel_Blue = 3279; % m3/TJ from EU Webpage (Blue one. Take a
    ↪ look on the NOTE, abode of the table on EU Article.
WF_e_f_Biodiesel_Green = 134345; % m3/TJ from EU Webpage (Green one)
WF_Construcion_Biodiesel = 1; % m3/TJ from EU Webpage
WF_Operation_Biodiesel = 0; % m3/TJ
E_Biodiesel_TJ = E_Biodiesel*3600; % TJ

WF_Total_Biodiesel_IT_Blue= ((WF_e_f_Biodiesel_Blue +
    ↪ WF_Construcion_Biodiesel + WF_Operation_Biodiesel)*E_Biodiesel_TJ)
    ↪ /1000000; % Million m3/year
WF_Total_Biodiesel_IT_Green = ((WF_e_f_Biodiesel_Green +
    ↪ WF_Construcion_Biodiesel + WF_Operation_Biodiesel)*E_Biodiesel_TJ)
    ↪ /1000000; % Million m3/year

figure(7);
plot(Time, WF_Total_Biodiesel_IT_Blue,'-b',Time,
    ↪ WF_Total_Biodiesel_IT_Green ,'-g')
legend('WF Biodiesel (Blue )','WF Biodiesel (Green)');
xlabel('Tiempo (year)'); ylabel('Water Footprint million (m3/year)');

WF_Total_Biodiesel = WF_Total_Biodiesel_IT_Blue +
    ↪ WF_Total_Biodiesel_IT_Green; % Million m3/year


E_Total_NoRenowable = E_Coal + E_Fuel + E_Natural_Gas + E_Nuclear; % +
    ↪ E_Hydro_TWh + E_Wind_Twh + E_Solar_Twh + E_Biodiesel; % Twh
```

```
E_Total_Renowable = E_Hydro_TWh + E_Wind_TWh + E_Solar_TWh + E_Biodiesel;
    ↪ % Twh
E_Total_ESP= E_Total_Renowable + E_Total_NoRenowable;

WF_Total_ESPANA = WF_Total_Coal_IT + WF_Total_Fuel_IT +
    ↪ WF_Total_Natural_Gas_IT + WF_Total_Nuclear_IT ...
    + WF_Total_Hydro + WF_Total_Wind + WF_Total_Solar + WF_Total_Biodiesel;

figure(8);
plot(Time,WF_Total_Hydro,'--b',Time, WF_Total_Wind, '--k', Time,
    ↪ WF_Total_Solar,'--m',Time,WF_Total_Biodiesel_IT_Blue,'--y',Time,
    ↪ WF_Total_Biodiesel_IT_Green, '--g');
set(gca, 'YScale', 'log')
xlabel('Tiempo (year)'); ylabel('Water Footprint (Million m3/year)');
legend('Water Footrpint Hydro','Water Footrpint Wind','Water Footprint
    ↪ Solar','Water Footprint Blue component','Water footprint Green
    ↪ component');


figure(9);
plot(Time,E_Hydro_TWh,'--b', Time,E_Wind_TWh,'--k', Time,E_Solar_TWh,'--m'
    ↪ ,Time,E_Biodiesel,'--g');
xlabel('Tiempo (year)'); ylabel(' Electricity Production (Twh/year)');
legend('Hydro ', 'Wind', 'Solar', 'Biodiesel');


figure(10);
plot(Time,E_Total_ESP,'-r');
xlabel('Tiempo (year)'); ylabel(' Electricity Production (Twh/year)');
legend('Total Eletricity Production in Spain frol All sources from
    ↪ 1990-2018 ');

figure(11);
plot(Time,WF_Total_ESPANA,'--b');
xlabel('Tiempo (year)'); ylabel('Water Footprint (Million m3/year)');
legend('Total WF in Spain frol All sources from 1990-2018 ');

figure(12);
plot(Time,WF_Total_ESPANA,'-b', Time , WF_Total_Coal_IT,'-r', Time ,
    ↪ WF_Total_Fuel_IT ,'-k', Time , WF_Total_Natural_Gas_IT ,'-g', Time ,
    ↪  WF_Total_Nuclear_IT ,'-m',Time,WF_Total_Hydro,'--k',Time,
    ↪ WF_Total_Wind, '--m', Time, WF_Total_Solar,'--r',Time,
    ↪ WF_Total_Biodiesel_IT_Blue,'--b',Time, WF_Total_Biodiesel_IT_Green,
    ↪ '--g');
set(gca, 'YScale', 'log')
xlabel('Tiempo (year)'); ylabel('Water Footprint (Million m3/year)');
```

```
legend('Total WF in Spain frol All sources from 1990-2018 ' ,'WF Coal' ,'
    ↪ WF Oil' ,'WF Natural Gas' ,'WF Nuclear','Water Footrpint Hydro' ,'
    ↪ Water Footrpint Wind' ,'Water Footprint Solar', 'Water Footprint
    ↪ Blue component' ,'Water footprint Green component');


for i = 1 : length(Time)
    Kwh_WF(i) = WF_Total_ESPANA(i)/E_Total_ESP(i);
end

Kwh_WF = Kwh_WF*0.001;

figure(14);
plot(Time,Kwh_WF,'-m');
xlabel('Tiempo (year)'); ylabel('m3/Kwh: (m3 of Blue and Green WF)')
legend(' WF of 1 Kwh eletricity ')


WF_Total_No_Renowable = WF_Total_Coal_IT + WF_Total_Fuel_IT +
    ↪ WF_Total_Natural_Gas_IT + WF_Total_Nuclear_IT;

WF_Total_Renowables = WF_Total_Hydro + WF_Total_Wind + WF_Total_Solar +
    ↪ WF_Total_Biodiesel_IT_Blue ;

figure(15);
plot(Time, WF_Total_ESPANA,'-b', Time , WF_Total_No_Renowable,'-m', Time ,
    ↪  WF_Total_Renowables ,'-k', Time, WF_Total_Biodiesel_IT_Green, '-g')
    ↪ ;
% set(gca, 'YScale', 'log')
xlabel('Tiempo (year)'); ylabel('Water Footprint (Million m3)');
legend('Total Blue WF in SPAIN frol All sources from 1990-2018 ' ,' Total
    ↪ Blue WF of No Renowable sources ' ,'Total Blue WF of Renowable
    ↪ sources',' Total Green WF in Andalusia ');
```

8 Anexo II

```
% % % CALCULATING THE FRACTIONS % % %
% % % The FRACTIONS called ALFAS % % %

% % ALFA NO RENOWABLE % %
Time = [ 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
    ↪ 2013 2014 2015 2016 2017 2018];
```

```
E_Coal_hard = [ 67.61 59.84 69.50 64.60 68.59 69.03 58.24 64.42 45.38
    ↪ 34.02 24.05 39.98 52.05 37.70 40.87 48.13 34.59 42.56 35.60]; % TWH:
    ↪  (ESPA[U+FFFD]A)
E_Coal_brown = [11.482 10.427 11.678 10.123 10.519 10.024 8.496 8.373
    ↪ 3.333 1.887 1.282 4.001 3.022 2.244 2.933 3.238 1.846 2.564 1.738];
    ↪ %TWH (ESPA[U+FFFD]A)
E_Coal = E_Coal_hard+E_Coal_brown;

E_Petrol = [22.578 24.632 28.593 24.002 23.839 24 23.829 18.508 18.002
    ↪ 19.242 16.562 14.692 15.321 13.763 14.121 17.241 16.921 15.766
    ↪ 14.498]; %TWh (ESPA[U+FFFD]A)
E_Natural_Gas = [20.178 23.358 32.386 39.368 55 79.011 91 94.799 120.798
    ↪ 107.746 94.851 85.508 73.308 57.536 47.273 52.498 53 64.037 58.004
    ↪ ]; %TWh (ESPA[U+FFFD]A)
E_Nuclear =[62.206 63.708 63.016 61.875 63.606 57.539 60.126 55.103 58.973
    ↪  52.761 62 57.718 61 56.726 57.305 57.196 58.633 58.039 55.766]; %
    ↪ TWh (ESPA[U+FFFD]A)
E_Total_No_Renowable = E_Coal + E_Petrol + E_Natural_Gas + E_Nuclear;

% Alfa_Coal = E_Coal/E_Total_No_Renowable;
% Alfa_Oil = E_Petrol/E_Total_No_Renowable;
% Alfa_Natural_Gas = E_Natural_Gas/E_Total_No_Renowable;
% Alfa_Nuclear = E_Nuclear/E_Total_No_Renowable;

E_Andalusia_No_Renowable = [20026.7 19951.8 23330.7 24331.4 29025.4 39950
    ↪ 39060.2 40123.4 34329.8 32714.4 29330.9 28922.4 28074.1 22240.5
    ↪ 20439.2 24887.9 20995.6 25281.1 23784.8]*0.001; % is multiplicated
    ↪ to 0.001 to convert the Gwh to Twh

E_Andalusia_Renowable = [ 1131.7 1792 1886 2334 2327.3 2517.3 2335.8
    ↪ 2627.7 4386.8 7615.2 10170.4 11250.7 ...
    11664.2 14063.5 12937.1 12354.4 13230.7 13467.5 12187.2]*0.001; %is
        ↪ multiplicated to 0.001 to convert the Gwh to Twh


for i = 1 : length(Time)
    Alfa_Coal(i) = E_Coal(i)/E_Total_No_Renowable(i);
    Alfa_Oil(i) = E_Petrol(i)/E_Total_No_Renowable(i);
    Alfa_Natural_Gas(i) = E_Natural_Gas(i)/E_Total_No_Renowable(i);
    Alfa_Nuclear(i) = E_Nuclear(i)/E_Total_No_Renowable(i);
        E_Coal_ANDALUSIA(i) = Alfa_Coal(i)*E_Andalusia_No_Renowable(i);
        E_Fuel_ANDALUSIA(i) = E_Andalusia_No_Renowable(i)* Alfa_Oil(i);
        E_Natural_Gas_ANDALUSIA(i) = E_Andalusia_No_Renowable(i) *
            ↪ Alfa_Natural_Gas(i);
        E_Nuclear_ANDALUSIA(i) = Alfa_Nuclear(i) * E_Andalusia_No_Renowable
            ↪ (i);
end
```

```
% %
 Time = (Time)'; Alfa_Coal = (Alfa_Coal)';Alfa_Oil = (Alfa_Oil)';
    ↪ Alfa_Natural_Gas = (Alfa_Natural_Gas)'; Alfa_Nuclear = (
    ↪ Alfa_Nuclear)';% transformar vectores filas en vectores columnas
 Years = [Time]; Alfa_Coal = [Alfa_Coal]; Alfa_Oil = [Alfa_Oil];
    ↪ Alfa_Natural_Gas = [Alfa_Natural_Gas]; Alfa_Nuclear = [Alfa_Nuclear
    ↪ ];
 table(Years, Alfa_Coal,Alfa_Oil,Alfa_Natural_Gas,Alfa_Nuclear)


% % % ALFA RENOWABLE % % %

E_Hydro_TWh = [ 31.81 43.86 26.27 43.90 34.44 23.02 29.83 30.52 26.14
    ↪ 29.16 45.51 32.91 24.16 41.05 42.97 31.37 39.87 21.07 36.80]; % TWh
    ↪ (ESPA[U+FFFD]A)
E_Wind_TWh = [4.73 6.76 9.34 12.08 15.70 21.18 23.30 27.57 32.95 38.12
    ↪ 44.27 42.92 49.47 55.65 52.01 49.33 48.91 49.13 50.90]; % TWh (
    ↪ ESPA[U+FFFD]A)
E_Solar_TWh = [0.01 0.02 0.02 0.02 0.02 0.05 0.12 0.52 2.58 6.06 7.19 9.40
    ↪  11.97 13.10 13.67 13.86 13.64 14.40 12.74]; % TWh (ESPA[U+FFFD]A)
E_Biodiesel_Solid = [1.18 1.30 2.11 2.43 2.50 2.03 2.17 2.29 2.67 2.96
    ↪ 3.17 3.81 4.11 4.83 4.51 4.78 4.78 5.14 4.98]; % Twh (ESPA[U+FFFD]A)
E_Biogas = [0.32 0.33 0.47 0.76 0.82 0.62 0.60 0.61 0.58 0.53 0.85 0.80
    ↪ 0.87 0.97 0.91 0.98 0.91 0.94 0.92]; % Twh (ESPA[U+FFFD]A)
E_Biodiesel = E_Biodiesel_Solid + E_Biogas; % TWh/Year(ESPA[U+FFFD]A)

E_Total_Renowable = E_Hydro_TWh + E_Wind_TWh + E_Solar_TWh + E_Biodiesel;

% Alfa_Hydro = E_Hydro_TWh/E_Total_Renowable;
% Alfa_Wind = E_Wind_TWh/E_Total_Renowable;
% Alfa_Solar = E_Solar_TWh/E_Total_Renowable;
% Alfa_Biodiesel = E_Biodiesel/E_Total_Renowable;

E_TOTAL_Andalusia = E_Total_No_Renowable + E_Total_Renowable;


for i = 1 : length(Time)
    Alfa_Hydro(i) = E_Hydro_TWh(i)/E_Total_Renowable(i);
    Alfa_Wind(i) = E_Wind_TWh(i)/E_Total_Renowable(i);
    Alfa_Solar(i) = E_Solar_TWh(i)/E_Total_Renowable(i);
    Alfa_Biodiesel(i) = E_Biodiesel(i)/E_Total_Renowable(i);
          E_Hydro_TWh_ANDALUSIA(i) = E_Andalusia_Renowable(i)*Alfa_Hydro(i
              ↪ );
          E_Wind_TWh_ANDALUSIA(i) = E_Andalusia_Renowable(i) * Alfa_Wind(i
              ↪ );
```

```
          E_Solar_TWh_ANDALUSIA(i) = Alfa_Solar(i) * E_Andalusia_Renowable
             ↪ (i);
          E_Biodiesel_ANDALUSIA(i) = Alfa_Biodiesel(i)*
             ↪ E_Andalusia_Renowable(i);
end

% %
 Time = (Time)'; Alfa_Hydro = (Alfa_Hydro)';Alfa_Wind = (Alfa_Wind)';
    ↪ Alfa_Solar = (Alfa_Solar)'; Alfa_Biodiesel = (Alfa_Biodiesel)';%
    ↪ transformar vectores filas en vectores columnas
 Years = [Time]; Alfa_Hydro = [Alfa_Hydro]; Alfa_Wind = [Alfa_Wind];
    ↪ Alfa_Solar = [Alfa_Solar]; Alfa_Biodiesel = [Alfa_Biodiesel];
table(Years, Alfa_Hydro,Alfa_Wind,Alfa_Solar,Alfa_Biodiesel)
```