SOLAR POWER PLANTS IN THE EU. AN ENVIRONMENTALLY-FRIENDLY ENGINE FOR THE EUROPEAN ECONOMIES

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Abstract: *We establish that the European Union is facing severe ecological problems, by analysing the ecological footprint of selected member states. Many of these problems are related to carbon and carbon equivalent emissions, some of which are generated by fossil fuel power plants. It is then shown that the European Union has potential in the solar power renewable energy sector. Finally, we calculate roughly how much land would be necessary in order to replace fossil fuel power plants, as well as nuclear plants, which are largely seen as environmentally dangerous. It is concluded that developing this alternative energy sector would help improve the ecological sustainability of the Union, by diminishing a significant part of its carbon footprint.*

Keywords: Solar power; carbon footprint; fossil fuels; alternative energy; ecological sustainability; sustainable development

INTRODUCTION

The European Union boasts some of the most performant economies in the world. Eight countries out of the first twenty (GDP/capita at purchasing power parity) are members of the EU (*cf.* CIA 2014). The same is true for the first twenty countries in the world, HDI wise (*cf.* UNDP 2013). One could, therefore, say that, at least in certain parts of the European Union, human welfare is at very high levels. While that may be true for the here and now, we might be entitled to ask what the costs were for achieving this status?

One of the main issues facing humankind in the XXI century is the sustainability of its natural environment. How well is the EU faring with regard to this objective? This paper seeks to analyse this part of the sustainability agenda of the Union, with a specific focus on the development of solar power potential, in order to lessen the carbon footprint of Europeans.

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1. ECOLOGICAL SUSTAINABILITY IN THE EU[1]

The easiest way to gauge the ecological sustainability of a country is by analysing its ecological footprint. This reflects the pressure exerted by nations on the regenerative capacity of the environment, and, to a larger extent, the biosphere.

Table 1 – Ecological footprint data for 25 EU member states

Country*	Ecological footprint of consumption	Biocapacity	Gross ecological footprint
Austria	5.3	3.31	-1.99
Belgium	8	1.34	-6.66
Bulgaria	4.07	2.13	-1.94
Croatia	3.75	2.5	-1.25
Czech Rep.	5.73	2.67	-3.06
Denmark	8.26	4.85	-3.41
Estonia	7.88	8.96	1.08
Finland	6.16	12.46	6.3
France	5.01	3	-2.01
Germany	5.08	1.92	-3.16
Greece	5.39	1.62	-3.77
Hungary	2.99	2.23	-0.76
Ireland	6.29	3.48	-2.81
Italy	4.99	1.14	-3.85
Latvia	5.64	7.07	1.43
Lithuania	4.67	4.36	-0.31
Netherlands	6.19	1.03	-5.16
Poland	4.35	2.09	-2.26
Portugal	4.47	1.25	-3.22
Romania	2.71	1.95	-0.76
Slovakia	4.06	2.68	-1.38
Slovenia	5.3	2.61	-2.69
Spain	5.42	1.61	-3.81
Sweden	5.88	9.75	3.87
United Kingdom	4.89	1.34	-3.55
EU aggregate	5.3	3.49	-1.81
* Data unavailable for Cyprus, Luxembourg and Malta.			

Source: GFN 2010 (data for 2007)

[1] Parts of the rationale put forward in this heading have been published in a previous article (*Implications of ecological footprint values for selected EU members* (2013), CES working papers, vol. 5, no. 4).

What we can infer from Table no. 1 is that 21 out of the 25 EU member states for which data was available are exerting more pressure on their environment than it can support. Only Estonia, Finland, Latvia and Sweden are existing within the carrying capacity of their natural environment. At an aggregate level, the European Union has overshot the carrying capacity of its environment by more than 50%. This is a clear statement that the European Union is on an unsustainable path, with regards to its natural environment.

This situation is perpetuated because other countries in the world are in effect exporting their carrying capacity. Countries dealing in agricultural exports and those having dense vegetation, which contribute to the planetary bio-chemical cycles (like Argentina, with its lush Amazonian jungle), are two such examples of countries which are in effect crediting other states with the carrying capacity of their environment. Even given this situation, the world at a whole is still unsustainable, as William Rees calculated that humankind has overshot the biocapacity of its environment by 30% (Rees 2010, p. 200).

Another thing to note about the numbers in the above table is that they reflect two situations: 1. humankind is using too many natural resources (putting a strain on the source side functions of the environment); 2. humankind is generating too much waste (putting a strain on the sink side functions of the environment). This means that, at least with regards to what the ecological footprint indicator measures, improving our mark on the environment would have to be a double undertaking: 1. use fewer natural resources 2. generate less waste. Both imply either a reduction in consumption or an increase in the efficiency of our consumption patterns; a third scenario combining both these effects is also possible.

One of the industry segments most reliant on natural resources, and therefore which contributes in an acute manner to the negative ecological footprint of the European Union is the energy sector. Regardless of what their fuel is, power plants require a high amount of natural resources and generally generate high amounts of waste (included in the term waste are both solids, like depleted uranium from nuclear fissile processes and gaseous CO_2 emissions, like those generated by conventional coal power plants). In this respect, one of the key industry sectors to act upon in order to mitigate our carbon footprint is the energy sector.

2. SOLAR POWER POTENTIAL IN THE EU

One of the emerging environmentally friendly energy technologies is the solar power plant (*e.g.* Swanson 2006, 2009). In line with other forms of renewable energy technologies, solar power plants promise both a more abundant input resource base and a lighter footprint on the environment. Their core unit is the photovoltaic cell, which needs sunlight in order to generate electricity, the efficiency of which is dictated by the materials used, the number of layers used, *etc*. As can be seen, the only natural resource input is sunlight, and this can roughly be computed, in order to ascertain the potential and feasibility of such a technology.

If we seek to analyse the European Union as a whole entity, one must sacrifice some of the precision of the model. With this in mind, we can compute a rough solar potential, although some areas might not conform to the calculations made herein. The starting point is the average solar irradiance received by the Earth, at ground level. This world-wide figure is roughly 184 Wm^{-2} (*cf.* Trenberth *et al.* 2009; world mean values closely resemble this figure: 182±6 Wm^{-2}, for 1981-1990, from Liepert 2002, p. 61-2; 184.8 Wm^{-2}, for the year 1985, from Stanhill and Cohen 2001, p. 263).

Given the fact that this figure is a world-wide scenario, which includes many tropical areas, we can assume a lower value for the European Union. Solar irradiance values for the EU range from under 100 Wm^{-2}, in the northern regions to as high 180 Wm^{-2} for areas close to the Mediterranean Sea. Therefore, an average yearly EU ground level solar irradiance value of around 130 Wm^{-2} would be close to reality (for measurements over a 30 year period in selected sites, see Ineichen (2011)).

For 2009, EU 27 generated 3,046 TWh (*cf.* EUROSTAT 2012). In Watts, this means an electricity generation of E_g =3.4 x 10^{11}. The power output of a photovoltaic module (be it solar panel or CPV) is given by the relation:

$$E_O = A \cdot \eta \cdot S_i ,$$

where E_o is the electricity output, A is the area occupied by photovoltaic (PV) modules, η is the conversion efficiency and S_i is the solar irradiance at ground level.

Given the fact that we seek to replace nuclear energy and fossil fuel power plants, E_o is equal to 83.11% · E_g (nuclear power has a 27.77% share in electricity generation and fossil fuels have a 55.34% share). S_i is set at an yearly average of 130 Wm^{-2}. This leaves the conversion factor η. This can vary depending the technology chosen, from as little as 5%, for organic PV modules to as much as 31% for concentrated photovoltaic technology (CPV) (*cf.* SunShot 2012, p. 83). CPV technology is used in solar farms, and is therefore a comercial undertaking, while common, household affordable PV modules normally have a η value of 16-18%.

This establishes the logical premise for 3 possible cases: one in which all electricity is generated via large scale CPV farms, one in which all electricity is generated via rooftop or small-scale installations and a third, where some electricity is generated by CPV farms and some by household small-scale PV installations. We deem this last case realistic and arbitrarily set a 70% to 30% ratio between large scale and small scale installations. This means that in order for solar plants to substitute nuclear and fossil fuel plants, the following conditions must be met:

$$0.7 \cdot 0.8311 \cdot 3.4 \cdot 10^{11} = A_1 \cdot 0.31 \cdot 130$$

$$0.3 \cdot 0.8311 \cdot 3.4 \cdot 10^{11} = A_2 \cdot 0.16 \cdot 130$$

where A_1 is the area occupied by CPV modules, and A_2 is the area occupied by small scale PV modules. Thus, we can define the total area to be taken up by PV modules, in order to substitute for nuclear and fossil fuel plants as:

$$A = A_1 + A_2 = \frac{0.7 \cdot 0.8311 \cdot 3.4 \cdot 10^{11}}{0.31 \cdot 130} + \frac{0.3 \cdot 0.8311 \cdot 3.4 \cdot 10^{11}}{0.16 \cdot 130}$$

This yields a total area value of $A=8.9 \cdot 10^9$ m^2 or $8.9 \cdot 10^3$ km^2. This means that in order to generate the same amount of electricity as done in 2009, for EU 27, via solar plants, an area roughly the size of the Island of Corsica would have to be fitted with PV modules.

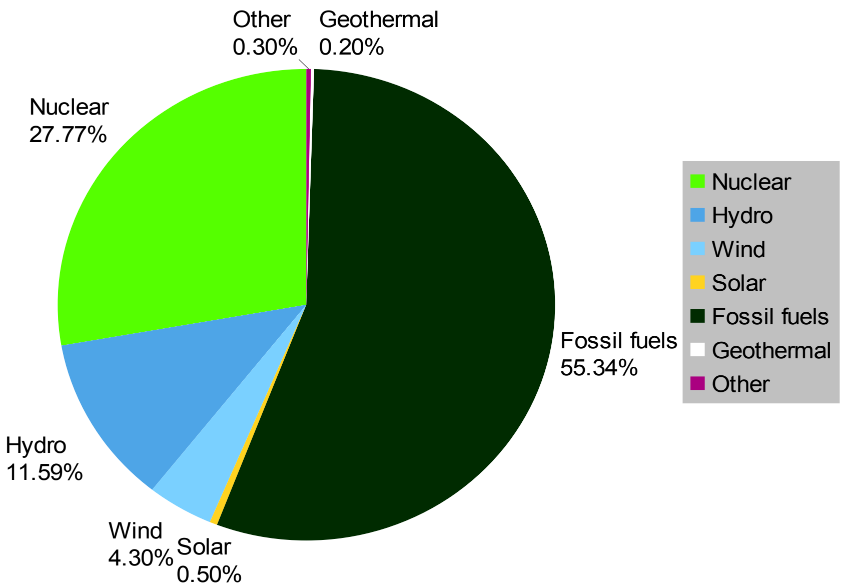
The analysis conducted up to this point does not include a cost analysis; however grid parity for solar-generated electricity is quickly approaching (already some areas of the world, situated in highly favored geographical positions, have reached grid parity – *cf.* See Breyer *et al.* (2009) for a brief analysis on EU and USA; see Denholm *et al.* (2009) for an analysis on USA; see also Branker *et al.* (2011); this, however, might not be enough, as some authors have correctly pointed out – *cf*. Yang (2010)).

A second thing to note is that the solar irradiance figure has a natural fluctuation. Seasonally, the solar irradiance is greater in summer than in winter. Also, solar irradiance drops to almost 0 during the night. Southern states receive more solar irradiance than Northern ones, and deserts more than covered landscapes. More-so, cvasi-predictible cloud formations can severely impact on the yearly amount of solar irradiance that the ground level sees. But as a yearly average, the figure put forward is a close approximation to the real thing. Another thing to note is that solar panels generate direct current, and this has to be transformed to alternative current in order to be fed into the main power grid. Some studies place losses due to this process to as high as 23% (*cf*. Denholm *et al*. 2008, p. 3).

3. IMPROVING THE ECOLOGICAL SUSTAINABILITY OF THE UNION THROUGH SOLAR POWER

Capitalizing on the solar potential of the European Union can bring significant benefits for the European community, and to a larger extent, the global community. First, if developing the solar power industry sector is done with replacing old fossil fuel power stations, than this can lead to a significant reduction in the carbon footprint of the Union. Currently, the European Union is most dependent on fossil fuels (mostly coal and natural gas) for meeting its electricity demand.

Figure 1 – Electricity production structure in EU-27, 2009



Source: EUROSTAT (2012)

This means that, given an appropriate energy transmission infrastructure all around the European Union (*i.e.* a supergrid), fossil fuel power plants could be replaced by solar plants. More-so, given the fact that nuclear facilities are not deemed ecologically sustainable, 28% of electricity, generated via these methods, could also be transferred to solar panels. Making these replacements would have a double effect, with regards to ecological sustainability:

1. the carbon footprint of the EU would see a significant drop. The two top contributors to carbon equivalent gases output in the atmosphere are, at this moment, the transport sector and electricity sector. While manufacturing and installing the needed solar panels does indeed come with a carbon price, there are no additional carbon costs, as in those brought about by raw materials in conventional power plants.

2. decommissioning nuclear plants is on the agenda of some European countries, due to the potential dangers of a core meltdown and similar accidents. Germany, for example plans to phase out all nuclear power from its electricity generation by the year 2021. Although nuclear plants are technically safe and reasonably environmentally-safe, the dangers of accidents are forever present and the costs, due to such accidents, very high. *Ergo*, replacing nuclear plants with solar farms could eliminate this potential threat.

The effect on the carbon footprint of the EU can be further analysed. For EU-15 2011, the public electricity and heat production sector has generated

$PEHP_{EU15CF}$= 861.521 Gg[2] CO_2 equivalent (own calculations based on ∑ 1A1a rows in table 1.9 of EC (2013a, p. 73)). The carbon footprint of the EU28 (latest data for 2011) can be deduced from published reports. Since EC (2013b) aggregates: 1. *public electricity and heat production* with 2. *petroleum refining* and 3. *manufacture of solid fuels and other energy industries*, in computing a EU-28 2011 carbon footprint value, there is a significant overlap between the value desired (public electricity and heat production) and other values quantified by the report authors (petroleum refining and manufacture of solid fuels and other energy industries). More so, the last report aggregates these 3 industry sectors, but differentiates between CO_2, CH_4 and N_2O. In other words, there is an aggregation and overlap issue, given by the 3 industry sectors and a differentiation problem, since EC (2013a) gives results in CO_2 equivalent units, and EC (2013b) gives results differentiated in 3 different gas units.

Therefore, in order to compute a *grosso modo* figure for the public electricity and heat production sector of the EU-28, for the year 2011, one must first normalize the values in the two reports. This is done by resolving the differentiation problem with this equation:

$$PEHPPRM_{EU15CF} = CO_2 + CH_4 \cdot \alpha + N_2O \cdot \beta ,$$

where $PEHPPRM_{EU15CF}$ is the carbon footprint of EU-15 public electricity and heat production, petroleum refining and manufacture of solid fuels and other energy industries sector, for the year 2011, CO_2 are the carbon emissions resulting from these activities, CH_4 are the methane emissions, α is the methane to carbon dioxide conversion factor, N_2O are the nitrous oxide emissions and β is the nitrous oxide to carbon dioxide conversion factor. Using the greenhouse gas equivalences calculator provided by U.S. Environmental Protection Agency (USEPA 2014), this yields a value of $PEHPPRM_{EU15CF}$ of 1,041,372.95 Gg CO_2 equivalent (values for CO_2, CH_4 and N_2O from EC (2013b, pp. 79-81)).

Next, we can calculate the ratio of public electricity and heating to the aggregate 3 industry sectors indicator put forward by EC (2013b). This ratio $PEHP_{EU15CF}/PEHPPRM_{EU15CF}$ is equal to 861,521/1,041,372.95 and yields a value of roughly 83%. This means that for 2011, EU-15, the ratio of public electricity and heating carbon footprint to public electricity and heating, petroleum refining and manufacture of solid fuels and other energy industries is roughly 83%. Based on this figure, we can make a hazardous, but necessary equivalence of 83% as the ratio between the same variables, but for the whole Union (EU-28). This is necessary in order to compute a rough, but likely EU-28 2011 carbon footprint from public electricity and heating. With this caveat in mind, the final figure is 0.83 $\cdot$ $PEHPPRM_{EU28CF}$, where the last term is equal to 1,412,587.39 (computed using ∑ EU-28 rows and columns 2011 from tables 14-16 *cf.* EC (2013b, pp. 79-81); conversions made using USEPA (2014)). This means that for 2011, EU-28, the amount of CO_2 equivalent gases generated by the public electricity and heat production industry sector was on the order of 1,412,587.39 Gg.

[2] Gigagrams (10^9 g).

It would be a difficult undertaking to determine exactly how much of this value is generated by fossil fuel and nuclear power plants. Out of these two, the carbon footprint of nuclear plants is negligible, in comparison to fossil fuel power plants (see Table no. 2). Even out of the total figure, it is highly likely that fossil fuel power plants make up for at least 80% of the carbon footprint. This is because hydro, nuclear and wind power have very low carbon footprints. Geothermal power is also negligible, with regards to carbon equivalent emissions. Solar power has a somewhat distinct carbon footprint, but, as figure 1 shows, solar power is not well represented in the current electricity generation processes of EU-28. An educated guess would be made even harder by the fact that, even though fossil fuel power plants have the greatest carbon footprint, this varies if we distinguish between coal-based, oil-based and natural gas-based plants. More so, some plants have implemented carbon capture and storage technology, further reducing their carbon footprint. Given these obstacles, we could none-the-less place the carbon footprint contribution of fossil fuel plants in EU-28 to somewhere in between 80% and 90% of the computed value. In order to further substantiate our claim, we direct the reader to table 2.

The previous table is significant in showing that fossil fuel, and in particular coal power plants have a very high carbon footprint, when compared to all other technologies. This means that for 1 kWh_{el} generated from coal, on average 9 kWh_{el} can be generated from photovoltaic modules, with the same carbon footprint. Other technologies would be even more carbon-friendly (like wind and hydro), however their resource base is highly specific. Solar power on the other hand is, more or less, ubiquitous although even in such cases some areas show more potential than others. Nuclear power, although benefiting from almost 50% of the carbon footprint of photovoltaic modules can raise severe ecological problems, in case of accidents.

Table 2 - Carbon footprints of major fuels

Electricity technology	**g CO_2-e/kWh_{el}**
Nuclear	62.5
Coal	993
Natural gas	664
Wind turbines	21
Photovoltaics	106
Hydro	15

Source: Adapted from Lenzen (2008, p. 8). Some of the values have been aggregated into average values

Also, one last thing should be noted: photovoltaic modules are a somewhat novel technology, and significant increases both in conversion efficiency and in input materials are expected (*e.g*. Curtright *et al*. 2008). And, since the bulk of the carbon footprint of solar panels is generated in the production process, once silicon is replaced as a main constituent, a significant decrease in CO_2 equivalent emissions is expected.

Another shortcoming of our carbon footprint analysis is the fact that our data refers to public electricity and heat generation. Given the fact that we have not analysed solar thermal power, this naturally inflates the emissions from electrical power plants with those from heating plants. This shortcoming can be mitigated by including thermal solar power into the analysis. This remains, however, an undertaking for future research. Given all these assertions, it is entirely conceivable that replacing fossil fuel power plants and nuclear plants with solar plants, as given by the ratios 70/30, will yield a significant decrease in the carbon footprint of the European Union. Since, however, our CO_2 equivalent emissions are inflated with emissions from heat generation, determining an exact value for the mitigation caused by developing solar farms would be a risk-ridden undertaking.

These things said we must not overstate the role and benefits of solar power. Developing solar farms takes up land, approximations of which we have provided in the previous heading. This means that more natural land will be converted to built-up land, leading to an increased ecological footprint. Therefore, although lowered carbon emissions will clearly reduce the ecological footprint, raising the built-up surfaces of land will act as a counterbalance. Given the fact that solar farms are site-specific projects, it is entirely possible that areas rich in biomass might have to be cleared, in order to optimise the output of such projects.

CONCLUSIONS

Following the statements made in this paper, the conclusion is that lessening the carbon footprint of the European Union can be done by replacing fossil fuel power plants with solar farms. In order to achieve this, and to replace nuclear plants, which are also considered ecologically unsustainable, a surface area roughly the size of the Island of Corsica (or $8.9 \cdot 10^3$ km^2, to be exact) would have to be fitted with solar panels and concentrated photovoltaic parks (the ratio we chose was 70% of energy output generated by concentrated large scale photovoltaics and 30% by small scale solar panels). Union wide, for the year 2011, power plants (regardless of the fuel used) were responsible for an estimated 1,412,587.39 Gg of CO_2 equivalent emissions; a significant part of this value can be eliminated by replacing fossil fuel power plants with solar farms, as the carbon footprint of solar power technology is markedly lower than that of conventional fossil fuel ones.

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