ENVIRONMENTAL IMPACTS OF THE PRODUCTION OF ELECTRICITY

Comparative study of eight technologies of electrical generation

SUMMARY

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INDEX

1. Justification of the study 3

2. Objectives of the study 3

3. Authorship and promoters 4

4. Analysed systems of electricity production 5

5. Analysed environmental impacts 6

6. Methodology of the study: the LCA 7

7. Unit of measurement 8

8. Geographical field of the study 8

9. Results of the study 9

10. Analysis of the results by technologies 10

11. Analysis of the results by impact categories 11

1. Justification of the study

The electrical market can only work in an efficiently and transparent way if the final prices of electricity reflect the whole costs associated to their production and, among them, the cost of environmental and social damages caused.

However, the electrical market do not function this way given that **conventional sources only incorporate in their final prices the costs originated in the generation phase**, such as fuels, capital and operation costs, labour, taxes and insurances.

The economic costs involved in environmental and social impacts provoked by conventional sources are systematically externalized, so it means that they fall upon the society as a whole and not upon the concerned electricity consumers.

The externalization of these environmental and social costs not only distort the electrical market, penalizing those power sources of minor impact –renewables– and favouring the most striking –conventional sources–, but also discourage the companies that are provoking such damages from adopting measures to prevent them.

2. Objectives of the study

The objective of this study is to quantify in a scientific way the environmental and social impacts provoked by the different technologies of electrical generation.

The possibility of quantify and compare quantitatively such environmental impacts is the main novelty of this scientific work in relation to other previous studies that were limited to qualitative evaluation of impacts.

The quantification of these impacts will allow in a second stage –that is not included in this study, however we are now working in it– their economic valuation. Once the economic costs of these impacts are well known, it will be made a proposal for the complete internalization of such costs into the final prices of electricity. Only then, all the current inefficiencies that are distortioning the electrical market will be eliminated.

3. Authorship and promoters

This study is the result of two years of intense work carried out by a team of experts of AUMA, an independent and prestigious consultant company, with the participation in some revision tasks of teachers and professors of the University of Barcelona (UB), Politechnical University of Catalonia (UPC) and the University Rovira i Virgili (URV) in Tarragona.

This work has been promoted by seven Spanish Public Institutions, mentioned below, in collaboration with the Spanish Association of Renewable Energy Producers–APPA:

- Department of Industry, Commerce and Development of the Aragonese Autonomous Government.
- Catalonian Institute of Energy (Icaen) of the Autonomous Government of Catalonia.
- Society for Energetic Management of the Autonomous Government of Galicia.
- Department of Industry, Commerce, Tourism and Labour of the Autonomous Government of Navarra.
- Basque Organization of Energy (EVE) of the Autonomous Government of Basque Country.
- The Center for Energetic, Environmental and Technological Research (Ciemat), depending of the Central Ministry of Science and Technology.
- The Institute for Energy Conservation and Diversification (IDAE) depending of the Central Ministry of Science and Technology.

4. Analysed systems of electricity production

This study evaluates and compares eight production systems of electricity.

Conventional systems

- **Lignite**
  It is a fossil fuel with a relatively low calorific value and a big proportion of sulphur and inactive components.

- **Coal**
  It is a fossil fuel with a medium calorific value; this denomination includes a mixture of soft coal and anthracites

- **Fuel-oil**
  It is the main derivative of oil – a fossil fuel with a high calorific value – used to generate electricity.

- **Natural gas**
  It is also a fossil fuel with a high calorific value.

- **Nuclear**
  Nuclear power stations use several derivatives of natural uranium as a fuel.

Renewable systems[1]

- **Wind**
  This technology transforms the wind energy in a mechanical work that applied to an alternator generates electricity.

- **Smallhydro**
  This technology transforms the water energy in a mechanical work that, moving a turbine connected with an alternator, generates electricity. Smallhydro power stations are those with less than 10 MW.

[1] The study does not include biomass due to the complexity of studying the very different kinds of fuels, with different associated effects, included under this denomination.

- **Solar Photovoltaic**[2]
  This technology transforms the photonic energy of solar radiation in electrical energy.

5. Analysed environmental impacts

The analysed environmental impacts in this study are assembled in twelve big categories[3]:

- **Global warming**
- **Ozone layer depletion**
- **Acidification**
- **Eutrophication**
- **Heavy metal pollution**
- **Carcinogenic substances**
- **Winter smog**
- **Summer smog**
- **Generation of industrial wastes**
- **Radioactivity**
- **Radioactive waste**
- **Depletion of energy sources**

[2] The photovoltaic technology is still in a developing proccess and with a scarce level of industrial implantation, quite the reverse of the other technologies mentioned in the study. In spite of its inclusion in this study, PV cannot be compared with the others. Due to this, its analysis will be explained separately.
[3] This study has not considered those categories of impact with little scientific consensus as visual impact, noise, biodiversity, risks, depletion of non energetic resources, security and labour health, dismantling of installations and occupation of territories.

6. Methodology of the study: the LCA

The methodology used for the estimation of the environmental impacts of the energetic systems considered is the **Life Cycle Assessment (LCA).** This is an internationally recognized –ISO 14.040– environmental tool used to identify in an objective and rigorous way all the environmental impacts of a product, process or activity *from cradle to tomb,* that is to say, **along all phases of its life cycle –from the extraction of raw materials needed for its elaboration until its final management as a waste–.**

The study has analysed the following life cycle stages of the electrical generation systems:

- Obtain the fuel (mining and extraction).
- Treatment of the fuel (preparation).
- Transport of the fuel.
- Construction of the plant (works and equipments).
- Running the central (Production of electricity)

Next figure shows life cycle scheme analysed for the coal system:

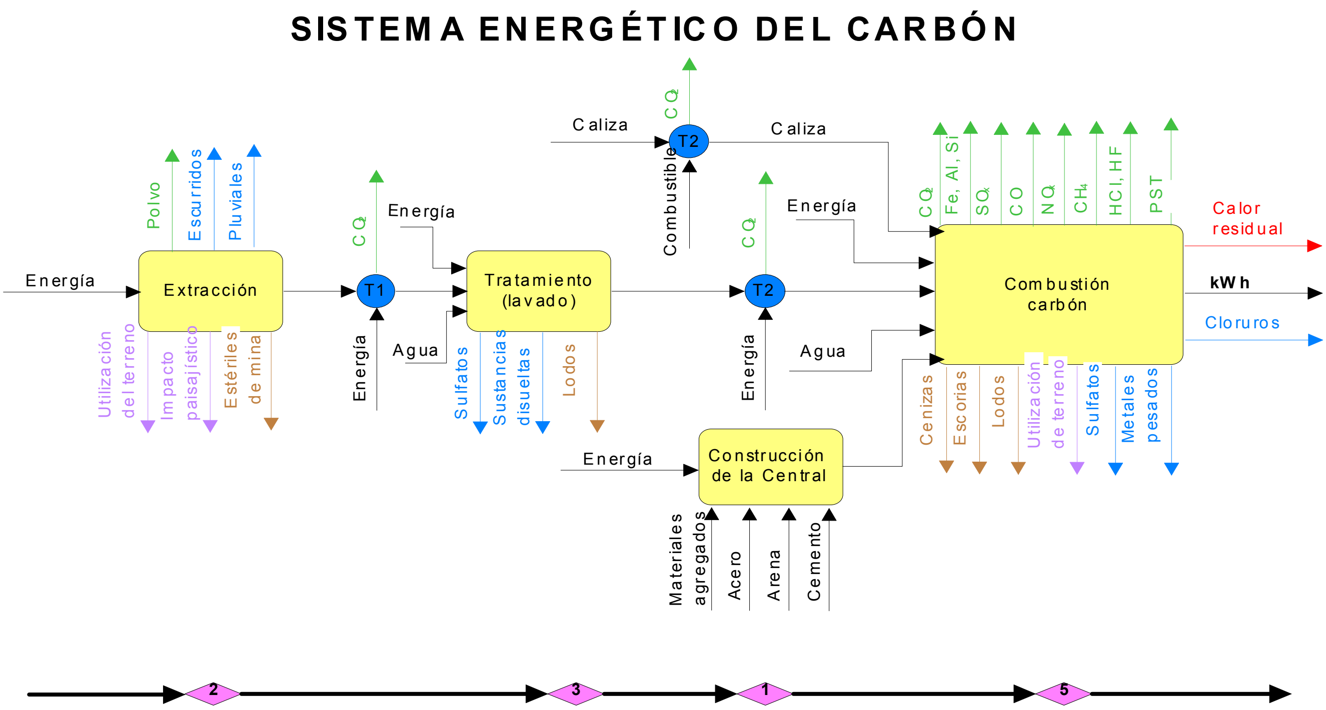

Figure 3: Analysis of coal energy system

The life cycle assessment of the eight studied systems of electricity generation has obligued to consider for each energy system 569 entrances –energy and raw materials– and exits –waste emissions– so there have been handled a total of **4.552 entrances and exits.** That means a big effort of search of very dispersed figures. Its treatment has needed to use a special software designed for this kind of studies, named Simapro.

The use of LCA has allowed to overcome the slimming fragmentations of previous studies that usually limited its analysis to the stage of the exploitation of the central.[4]

7. Unit of measurement

The unit used for measuring the environmental impacts of the eight analysed electricity generation systems is the ***Ecopoint.*** The study finishes giving to each studied technology a total value of ecopoints of environmental impact by Terajulius of produced electricity. (One Terajulius is on a level with 278 MWh).

It is very important to remark that the ***ecopoints*** **are units of environmental penalty**, so the more ecopoints obtain a generation system, the more environmental impact it will have and, on the contrary, the systems with the lowest ecopoint results will be the most friendly for the environment.

8. Geographical field of the study

The geographical field of this study is Spain[5]. In fact, this work is the first study of its type and in-depth research applied to the Spanish reality.

[4] This study do not analyse the stage of central dismantling due to the international lack of information about it. Electricity transportation and distribution, and final electricity usage have not been analysed either, since it has been understood that environmental impacts of such stages are the same for all the considered technologies.

[5] For the realization of the impact inventory related to the nuclear thermic systems and natural gas, as well as eolic and photovoltaic, it has been used information from european origin. Once the fossil wastes are analysed, the waste emissions that have place in the producer countries –mainly outside of the spanish territory–, have been evaluated too.

9. Results of the study

The wide experience of the authors in studies related to the environment and energy, the use of an internationally accepted environmental management tool –**Life Cycle Assessment ((LCA)**– and a proven software –Simapro– guarantee the reliability of the results

The results of the study in terms of ecopoints are as follows:

- The electricity generation systems based on traditional fossil fuel –**lignite, coal and fuel-oil**– are the only ones that overcome the 1.000 ecopoints, so they result to be the most harmful for the environment.

Category 1- Total *ecopoints* higher than 1.000	
LIGNITE SYSTEM	1735
FUEL-OIL SYSTEM	1398
COAL SYSTEM	1356

- The electricity generation systems based on **nuclear energy and natural gas** are between 100 and 1.000 ecopoints, so that they are in an intermediate impact position.

Category 2- Total *ecopoints between* 100 and 1000	
NUCLEAR SYSTEM	672
NATURAL GAS SYSTEM	267

- The two systems based on renewable sources that have a higher grade of development and implantation in Spain –smallhydro and wind power– are the ones that present the smallest environmental impact, obtaining less than 100 ecopoints of impact[6].

Category 3- Total *ecopoints* lower than 100	
WIND SYSTEM	65
SMALLHYDRO SYSTEM	5

[6] The photovoltaic solar technology obtains 461 ecopoints of impact. This result must be seen with great reserves since PV technology is still in a developing proccess and with a scarce level of industrial implantation, quite the reverse of the other technologies mentioned in the study. The great amount of electricity required for manufacturing PV cells penalize its results given that the electrical mix used is dominated by nuclear and fossil sources.

10. Analysis of the results by technologies

The obtained results present a big concordance with the preponderantly existing opinions in the scientific community until now, based in previous evaluations: **the renewable sources of energy have, in general, a lower impact than the conventional ones.**

However, thanks to this study it is possible for the first time in Spain to quantify the difference of impacts between the different electricity generation technologies. From this comparative analysis, it is possible to take out the following conclusions:

- **The environmental impact of conventional energies is 31 times higher than the one of renewable energy sources.**[7]
- **To produce one kWh of electricity with the best renewable system –smallhydro– has an environmental impact:**
  - **300 times lower than the one produced with lignitum.**
  - **250 times lower in relation with the one generated with coal or petroleum.**
  - **125 times lower in relation with the one produced with uranium.**
  - **50 times lower than the one generated with natural gas.**

The big difference of environmental impact between conventional electricity generation systems and RES would have been higher if the study had not maintained an **attitude of not penalizing conventional systems**. For instance, the fact that the used information for analyse the smallhydraulic energy corresponds to big hydraulic centrals means that its impacts are oversized and therefore its results are penalized in terms of ecopoints.

The conventional sources of electricity generation would have been penalized if some other categories of impact had been considered, for instance**, the dismantling of plants, the occupation of soil, accident risks or waste heat generation.**

[7] The five conventional technologies of electricity generation sum up 5.452 ecopoints of impact. The two renewable technologies compared –eolic and smallhydraulic- sum up 70 ecopoints. If we compare both results by dividing the total of ecopoints by the number of included technologies in each block (5.452/5=1.090 y 70/2=35) we will obtain an impact relation of 31 to 1 in favour of renewable energy.

11. Analysis of the results by impact categories

The intensity of the impacts provoked by the different electricity generation systems for each of the twelve categories considered is represented in the following table. The analysis of distribution of its colours can show at first sight that the red and brown squares –impact with important and significant intensity, respectively– are concentrated in the left side of the table, that corresponding to the conventional sources, while the yellow and green colours –small and negligible impacts, respectively– concentrate in the right side, where RES are located.

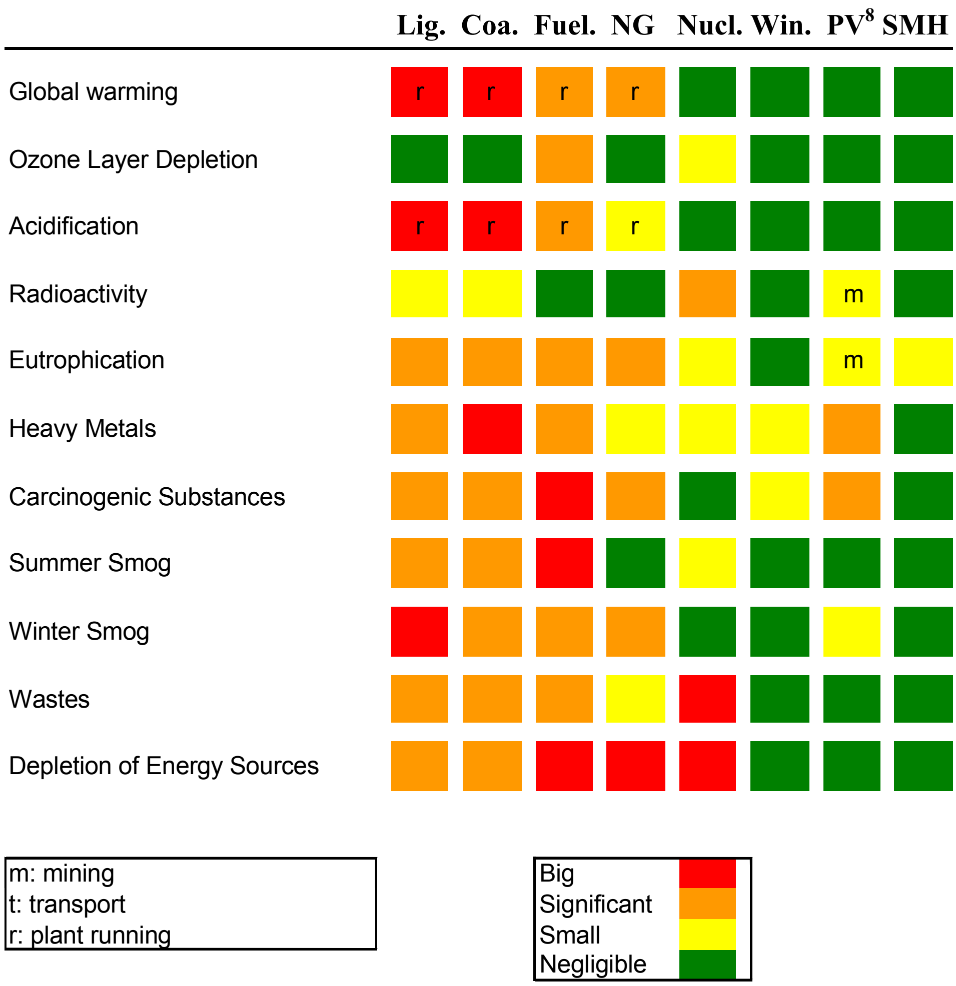

Figure 4: Matrix of environmental impacts by categories

8 The photovoltaic solar technology is still in a development way with a very limited level of industrial implantation, quite the reverse comparing with the other technologies considered in this study. The photovoltaic solar system can not be compared with the other energetic systems.

The following table quantifies in final ecopoints the environmental impacts by categories and energetic systems.

Impacts/Energetic Systems	lignite	Coal	Fuel-oili	Natural Gas	Nuclear	Wind	Smallhydro
Global Warming	135.00	109.00	97.00	95.80	2.05	2.85	0.41
Ozone Layer Depletion	0.32	1.95	53.10	0.86	4.12	1.61	0.05
Acidification	920.00	265.00	261.00	30.50	3.33	3.49	0.46
Eutrophication	9.83	11.60	9.76	6.97	0.28	0.27	0.06
Heavy Metals	62.90	728.00	244.00	46.60	25.00	40.70	2.58
Carcinogenic Substances	25.70	84.30	540.00	22.10	2.05	9.99	0.76
Winter Smog	519.00	124.00	135.00	3.08	1.50	1.48	0.15
Summer Smog	0.49	3.05	36.90	3.47	0.32	1.25	0.06
Radioactivity	0.02	0.05	0.02	0.00	2.19	0.01	0.00
Industrial Wastes	50.90	12.90	0.62	0.58	0.28	0.29	0.52
Radioactive Waste	5.28	10.60	7.11	1.34	565.00	1,83	0.32
Depletion of Energy Sources	5.71	5.47	13.60	55.80	65.70	0.91	0.07
TOTAL	**1735.15**	**1355.92**	**1398.11**	**267.11**	**671.82**	**64.67**	**5.43**

Figure 5: Table with final ecopoints by energy systems and impact categories.