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# EVALUATING THE ENVIRONMENTAL IMPACT OF DIFFERENT ENERGY SOURCES, FOSSIL OR ALTERNATIVE, THROUGH THE LIFE CYCLE ASSESSMENT METHOD

**Liana Bogatu** [1]

[1] Petroleum-Gas University of Ploiesti, Romania
email (corresponding author): lianabogatu@gmail.com

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## ABSTRACT

Energy is one of the most important components of a country's economy and development, and fossil fuels ensure 83.4 % of primary energy worldwide.

One of the most debated facts nowadays is the influence of the fossil fuels used as a main energy source, on climate change, in fact the $CO_2$ emissions released by these fuels. Therefore, alternative energy sources have been developed to reduce $CO_2$ emissions, respectively the impact of greenhouse gases, on the environment.

The present study proposes an objective evaluation of different types and sources of energy and a relevant method for assessment of the environmental impact of representative type of energy sources. Consequently, fossil fuels and alternative sources of energy, especially electricity, are evaluated by Life cycle assessment method. Specific power energy of each category of combustibles, as well as their specific emission of $CO_2$, $SO_x$ and $NO_x$, are highlighted and discussed.

The study emphasized that the impact of different energy sources has to be attentively analyzed in order not to actually generate more serious environmental consequences.

**Keywords:** energy, fossil fuels, environmental impact, life cycle assessment

## INTRODUCTION

Climate change is one of the main concerns nowadays and the most debated source, considered to influence climate change, is $CO_2$ emissions generated by the combustion of fossil fuels. There are many alternative sources and technologies aimed at partial or total replacement of fossil fuels. Some of these use electricity, solar energy, wind energy or hydro energy, from the use of which no $CO_2$ results [1,2,3]. Other technologies use renewable sources like biomass, which provide green fuels such as bioethanol, biodiesel, biogas, etc., which are used similarly to fossil fuels and release $CO_2$ [4,5,6].

$CO_2$ emissions are directly correlated with energy consumption and production. The transport, industry, agriculture, also the domestic energy consumption etc, have an important contribution. A high proportion, approx. 77% of greenhouse gas emissions, is due to energy consumption [7].

Energy consumption worldwide has grown at an accelerated rate since the 1950s, when global consumption was at a level of approximately 20,136 TWh, until now, when the global consumption is approximately 128 800 TWh, which means 6 times higher, than the referential point, 1950s [8].

Statistics show that between 2019 and 2021, primary energy demand increased by 5.8%, and fossil fuel consumption accounted for 82% of primary energy; renewable energy increased by over 1822.4 TWh [9, 10]. Considering the main energy consumers, the data reveals that: transport represents the most important share of consumption, namely a third of global energy consumption, agriculture approx. 10.55%, the industrial processes and the products' use, approx. 9.10%, waste management 3.32%, the rest, up to 100%, in various other fields and activities [11].

This paper aimed to evaluate representative energy sources; thus, the specific properties of different types of fuels, the specific of energy production processes, especially of electrical one, were taken into account. Statistical data and/or data obtained on the basis of specific chemical or combustion equations were also used and compiled the fundamental elements of a critical assessment.

The novelty of this study is the realistic valuation of the advantages and/or disadvantages of using different energy sources, based on concrete and objective data, by correlating their energy efficiency and environmental impact.

Also, a relevant and complex assessment method was used, which was applied to the life cycle assessment (LCA) of representative energy sources, especially the electricity used to power electric cars. LCA analysis is relevant for estimating the environmental impact of various products, processes, phenomena, etc. and is usually based on the quantitative elements of the life cycle of the subject being studied [12].

## CRITICAL STUDY OF THE MAIN SOURCES OF ENERGY

Considering that a high proportion of greenhouse gas emissions is due to energy consumption, and transport represents the highest rate, in this study we evaluated and highlighted the impact of different types of energy sources, especially of the one used in transport.

Energy is obtained from different sources and/or complex processes, the main categories being:

- Energy obtained from hard-to-regenerate sources represented by fossil fuels, respectively coal, crude oil and natural gas;
- Energy obtained from renewable sources, respectively, solar energy, hydro, wind energy;
- Electricity;
- Nuclear energy.

From the data published in "BP Statistical Review of World Energy 2022" regarding energy production from different sources, the following figures can be highlighted [3]:

- Energy production from fossil fuels (gas, oil, coal) represents approx. 83.4%;
- Hydroelectricity: approx. 9,6 %;

- Nuclear energy: approx. 2 %;
- Renewable energy: approx. 5 %.

It is easily observed that most of the energy produced worldwide comes from fossil fuels.

In 2021, fossil fuel energy consumption reached a total level of 136,018 TWh, structured according to the following configuration [8]:

- Energy obtained from Coal: 44,473 TWh (32.7%),
- Energy obtained from crude oil: 51,170 TWh (37.6%),
- Energy obtained from Gas: 40,375 TWh (29.7%).

A relatively balanced distribution can be observed between the three categories of fossil fuels, in first place being crude oil (represented by gasoline, diesel and heavy heating furnace fuel).

For the evaluation of the efficiency and environmental impact, of any fuel category, several elements are important, namely:

- The calorific value of the fuels, for evaluating energy efficiency;
- The specific content of carbon and hydrogen (especially for fossil fuels), which are the basis of combustion reactions and is correlate with the calorific value of the fuel;
- Greenhouse gas emissions ($CO_2$, $CH_4$, $N_2O$, water vapors), as well as $SO_x$ type emissions, for evaluating the impact on the environment;
- Availability of fuel naturally or, for certain categories, how expensive it is to obtain.

The calorific value of different types of fuels was highlighted based on the data from the field literature, or was calculated by the calculation formulas presented by the specialized literature in the field of combustion [13,14,15,16].

The percentage content of hydrogen (expressed in relation to the total number of hydrogen and carbon atoms in the fuel molecule), respectively the H/C ratio, was calculated based on the chemical structure of the fuels.

The chemical structure of complex fuels (gasoline, diesel, heating fuel, coal) was considered based on the average chemical composition of the fuels, respectively based on hydrocarbon classes structure, specific to the products, that are found in the literature in the field [17,18,19].

All these data and characteristics were centralized and are presented in a synthetic way in table no.1, for the representative fuels.

## RESULTS AND DISCUSSIONS

Analyzing the specific data presented in the above table, from the point of view of energy efficiency and environmental impact, we can highlight the following aspects:

- The value of the calorific power decreases from hydrogen and natural gas, towards coke, this having the lowest value; natural gas, respectively hydrogen, has the highest value.

- We can explain this "hierarchy" by the fact that, with the increase in the hydrogen content in an organic compound, the calorific value also increases: coke has the lowest hydrogen content, therefore the lowest calorific value; fuels obtained from crude oil have a significantly higher hydrogen content, and natural gas has a very high hydrogen content and consequently, the highest calorific value.
- From the point of view of environmental impact evaluation, respectively the volume of $CO_2$ emissions, it follows the combustion equation:

$$C_xH_y + \frac{x+y}{2} O_2 = x\ CO_2 + \frac{y}{2} H_2O \quad (1)$$

- Considering that $CO_2$ emissions are proportional to the carbon content, it is obvious that the largest volume of $CO_2$ emissions will be generated by coke, which has the highest carbon content; natural gas has the lowest volume of emissions and hydrogen has zero carbon emissions;
- Also, if we analyze among the fuel categories, other elements with negative effects on the environment and human health, such as the content of sulfur compounds and heavy metals compounds, coke has the most harmful impact, because it has the highest content of sulfur and compounds of heavy metals [22,23].

***Table 1***. *Characteristics of representative fuels*

| Crt. No. | Fuel type | Superior calorific value, MJ/Kg [ 6,7] | Hydrogen content, %*) | H/C Ratio |
|---|---|---|---|---|
| 1 | Hydrogen ($H_2$) | 120-142 MJ/kg | 100 | - |
| 2 | Methane ($CH_4$) | 50-55 MJ/kg | 25 | 4/1 |
| 3 | Natural gas | 42-55 MJ/kg | 24 | 3,8/1 |
| 4 | Liquefied petroleum gas (LPG) | 46-51 MJ/kg | 17-18 | 3,7/1 |
| 5 | Biogas (55-65% CH4) [20,21] | 28-30 MJ/kg | 15-17 | - |
| 6 | Gasoline | 44-46 MJ/kg | 14-15 | 1 / 2.5 |
| 7 | Diesel | 42-46 MJ/kg | 13-14 | 1/ 2.8 |
| 8 | Coal | 23.9 MJ/kg | < 3 | > 9 / 1 |
| 9 | Firewood | 16 MJ/kg | - | - |

*) the percentage is calculated in relation to the number of hydrogen and carbon atoms in the fuel molecule.

Summarizing the specific aspects of the analyzed fuels, it is very clearly observed that:

- coal-type fuels have the lowest energy efficiency and produce the highest level of pollution;
- hydrogen is in the first place, followed by natural gas, these having the highest energy efficiency and the lowest impact on the environment;
- gasoline and diesel products obtained from crude oil are in a medium to high position, but with twice the energy efficiency compared to coke and a much lower level of pollution.

Why is it important to analyze in depth all the specific aspects of using different types of fuels?

Because there is a close interdependence between fossil fuels and other types of fuels and/or alternative energies. Thus, fossil fuels are used both as such, for the large-scale production of energy, specifically over 83.4 % of the energy consumed worldwide [3], but also for the production of so-called "green" energy, such as electricity or hydrogen.

These alternative energy sources have been developed with the main goal of reducing environmental pollution. But is the result, exactly what was expected?

In order to be able to objectively evaluate the efficiency of these alternatives, both from the point of view of energy performance and environmental impact, a complete analysis of the life cycle of the respective energy sources must be carried out, from the initial stage of obtaining, until the last step, the concrete transformation into energy for consumption. In this respect, a Life cycle assessment analyze type is relevant.

In this study, such an analysis of an alternative source of energy used more and more in the field of transport, is carried out, respectively the case of electric powered cars.

## CASE STUDY AND DISCUSSIONS

### Life cycle assessment of the electric powered cars

Since transport represents the segment with the highest energy consumption (more than 33%), as previously presented, it was right that alternative technical solutions to reduce pollution should be developed in this field, the most widespread of which is that of cars powered by electricity. Thus, electric powered cars have registered a significant increase in the last 10 years, the most pronounced in Norway (approximately 80%) and the slowest in the USA (approximately 10%). In Germany, the growth was approximately 20%, at the level of the average growth recorded in the EU [24].

And yet, does the use of electric cars represent a real solution for reducing $CO_2$ emissions and reducing environmental pollution? Are all specific and related aspects taken into account?

Usually, the assessment of $CO_2$ emissions of electric cars is done by strictly considering only the energy consumption necessary to drive the car. From this point of view, indeed, electric cars practically do not generate $CO_2$ emissions. However, an LCA type analysis highlights all the elements that must be taken into account throughout the chain, from the sources of obtaining electricity, to storage, use, management and disposal of specific used materials, etc.

For an objective, realistic evaluation of the environmental impact of an electrically operated machine, all these components, as well as the related ones, must be evaluated, as shown by the analysis carried out in the present study, presented as follows.

- According to the data studied, over 60% of electricity is obtained from fossil fuels, and a large part, 20-40%, depending on the geographical area, is obtained from coal [27, 28]. As it was shown in the first part of the study, from the evaluation of the different types of fuels, it appears that coal has the lowest energy efficiency, so a double amount of coal is needed compared to gasoline, to achieve the same energy efficiency;

- The large volume of $CO_2$ and $SO_x$ emissions and the impact of compounds with heavy metals resulting from the combustion of coal used for the production of electricity are much higher than in the case of gasoline and diesel fuels [22, 23].
- The materials needed to make the cars' batteries, especially the rare metals that are obtained from the mining activity, require the consumption of huge amounts of energy, obtained from fossil fuels; the aspect of the low availability of these rare metals cannot be neglected either;
- The accumulation of an increasing number of used batteries, in the absence of viable recycling technologies, leads to a high impact of these toxic materials on the environment [25, 26].

Studies published in 2021 by researchers from the German institute Fraunhofer ISE (Fraunhofer-Institut für Solare Energiesysteme), as well as data published by the US Energy Information Administration in 2024, show that [27, 28]:

- a low-capacity electric car with only a 40 kwh battery that can be charged at a regular charging station needs to travel at least 72,600 km to have a $CO_2$ advantage over a gasoline/diesel car;
- a medium-capacity car, with a 56 kwh battery, must have a distance of at least 100,000 km, and
- for an Audi E-Tron type car, with a 95 kwh battery, a minimum of 166,000 km are required before it reaches a climate advantage compared to a diesel car.

For many specialists in the field, it is clear that the manufacture of high-powered electric cars that travel ever greater distances does not make sense.

All this LCA analysis highlights the fact that the evaluation of the efficiency of a process, a product, phenomenon, etc., must be done in its entirety, taking into account all aspects, both direct and indirect. Thus, in the case of electric cars, it is highlighted that their use is efficient for short distances, specific to city trips. In this way, the level of pollution in the city area is reduced, with the mention that the pollution will be transferred to the area where the power plant is located, because they usually work with fossil fuels, especially coal, which generates a high level of pollution.

## CONCLUSIONS

Environmental impact of $CO_2$ emissions are directly correlated with energy consumption and production. A high proportion, approx. 77% of greenhouse gas emissions, is due to energy consumption. Since transport represents the segment with the highest energy consumption (over 33%), various alternative technical solutions to reduce pollution have been developed in this field, the most widespread of which is that of electric cars.

To evaluate the efficiency of this alternative, as in other cases where the efficiency of a process, product, action, etc. is evaluated, in the present study a life cycle assessment (LCA) type analysis was performed. In the case of electric motors, the LCA type analysis showed that there are many elements that deny an important part of the expected advantages, in the direction of reducing the environmental impact Specifically, electric cars are proving to be particularly efficient for short-distance transportation within cities, reducing pollution in the city but transferring it to areas where power plants are located.

The fossil fuels continue to hold the most important share of the energy market worldwide and that will not be changed in the very next future. That is not a threat for the environment if the use of these resources is properly managed. The impact of different energy sources must be carefully assessed in order not to actually generate more serious environmental consequences.

## REFERENCES

[1] Wu X., Yin S., Cheng C., Wei X., Short term hydropower scheduling considering cumulative forecasting deviation of wind and photovoltaic power, *Applied Energy*, Volume 376, 15 December 2024, Article number 124199.

[2] Jung C., Sander L., Schindler D, Future global offshore wind energy under climate change and advanced wind turbine technology, *Energy Conversion and Management*, Volume 32, 1 December 2024, Article number 119075

[3] Herbert G.M, Iniyan S., Sreevalsan E., Rajapandian S., A review of wind energy technologies, Renewable and Sustainable Energy Reviews, Volume 11, Issue 6, August 2007, pp. 1117-1145.

[4] Gholizadeh T., Ghiasirad H., Skorek-Osikowska A., Life cycle and techno-economic analyses of biofuels production via anaerobic digestion and amine scrubbing CO2 capture, *Energy Conversion and Management*, Volume 321, 1 December 2024, Article number 119066.

[5] Khalil M., Berawi M.A., Heryanto R., Rizalie A., Waste to energy technology: The potential of sustainable biogas production from animal waste in Indonesia, Renewable and Sustainable Energy Reviews, Volume 105, May 2019, pp. 323-331.

[6] Sukphun P., Wongfaed N., Reungsang A., Assessing the potential of sugarcane leaf silage for enhanced methane production: Biochemical methane potential and kinetic analysis, Industrial Crops and Products, Volume 222, 15 December 2024 Article number 119550.

[7] https://science.nasa.gov/climate-change/faq/what-is-the-greenhouse-effect/

[8] Ritchie H, Rosado P., Roser M., "Fossil Fuels", Our world in data Journal, October 2022, https://ourworldindata.org/fossil-fuels#global-fossil-fuel-consumption

[9] BP Statistical Review of World Energy 2022, 71st edition, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[10] Energy Institute - Statistical Review of World Energy (2024), https://www.energyinst.org/statistical-review

[11] Transport's dependence on fossil fuels holding back the energy transition, New Energy World Magazine, 24 July 2024, https://knowledge.energyinst.org/new-energy-world/article?id=138927

[12] Hochschorner E., Finnveden G, Evaluation of two simplified life cycle assessment methods, Journal of Life Cycle Assessment, Vol. 8, 2003, pp. 119-128.

[13] Dobrinescu D., Procese de transfer termic si utilaje specifice, Editura Diactică şi Pedagogică, Bucuresti, 1983, pp. 37-40.

[14] https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx

[15] Erol M., Haykiri-Acma H., Küçükbayrak S., Calorific value estimation of biomass from their proximate analyses data, Renewable energy, Volume 35, Issue 1, January 2010, pp. 170-173.

[16] Ulbig P., Hoburg D., Thermochimica Determination of the calorific value of natural gas by different methods, Thermochimica Acta, Volume 382, Issues 1–2, 31 January 2002, pp. 27-35.

[17] Schobert H., Chemistry of Fossil Fuels and Biofuels, Cambridge University Press, 2013, pp. 174 – 191.

[18] Suciu G.C., Tunescu R., C., Ingineria Prelucrarii Hidrocarburilor, Vol I, Ed.Tehnica, 1983, pp. 31-37.

[19] Kaiser C.R, Borges J.L, Anderson R., Quality control of gasoline by 1H NMR: Aromatics, olefinics, paraffinics and oxygenated and benzene contents, Fuel, Volume 89, Issue 1, January 2010, pp. 99-104.

[20] Yin Li, Christopher P. A., Minji K., Composition and Toxicity of Biogas Produced from Different Feedstocks in California, Environ Sci Technol. 2019 Oct 1; 53(19): pp. 11569–11579.

[21] Chen X.Y., Hoang V.T, Ramirez A.A., Membrane gas separation technologies for biogas upgrading, The Royal Society of Chemistry Advances Journal, 2015, pp. 24439-24448.

[22] Meij R., Winkel H., The emissions of heavy metals and persistent organic pollutants from modern coal-fired power stations, Atmospheric Environment, Volume 41, Issue 40, December 2007, pp. 9262-9272.

[23] Lakhmir, M.A., Soomro, S.A., Unar, I.N., Akhter, F., Remediation of High Sulfur Coal Using Modified Alkali-Acid Hybrid Treatment for Reduced SOx, Low Mineral Content, and Enhanced Combustibility: Comparative Study, Philippine Journal of Science, Volume 153, Issue 3, June 2024, pp. 745 – 755.

[24] Ritchie H, Tracking global data on electric vehicles, Our World in Data Journal, February 2024.

[25] Lyu, W., Hu, Y., Liu, J., Deng, J., Zhang, S., Impact of battery electric vehicle usage on air quality in three Chinese first-tier cities, *Scientific Reports*, Volume 14, 1 December 2024, Article number 21.

[26] Bobeth S., Kastner I., Buying an electric car: A rational choice or a norm-directed behavior? Transportation Research Part F: Traffic Psychology and Behaviour, Volume 73, August 2020, pp. 236-258.

[27] https://www.iea.org/energy-system/electricity

[28] Electricity in the United States, US Energy Information Administration, March 2024, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php#:~:text=The%20three%20major%20categories%20of,geothermal%2C%20or%20solar%20thermal%20energy.

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