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Life-Cycle Environmental Footprint Analysis of Electricity Generation Technologies

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ABSTRACT

Increasing urbanization and global population, in addition to huge economic and industrial developments have jointly led to raised consumption of electrical. With the rise in fossil-based fuel costs and the environmental awareness to decrease greenhouse gas emissions there is an increasing requirement to alter away from CO2 emission creating fossil-based fuels to new renewable power resources for electrical generation. By using Life Cycle Assessment, this paper's scope is to compare and evaluation the chosen environmental effects associated with the electrical generation of the sustainable and the fossil-based system. In this paper, the environmental footprint that obtains from the diverse energy sources' exploitation/use, either renewable or conventional/fossil in the electrical generation industry, is analyzed. Analysis of the electrical energy generation sectors depended on diverse factors include a potency ecological effect categories' wide vary. Thus, the energy sources' diverse life cycle stages used in electrical generation are investigated. The pairwise comparison is presented for the needed data' derivation. For each of criteria, these comparison is applied for deriving weights of criteria' significance and alternatives' relative rankings. Each technology's ecological effect according to all factors are calculated. Finally, the eco-friendliest and the most environmentally damage technologies are determined.

1. Introduction

The energy has important impacts in the evolution of technology and economy. Electrical was the main role during the passage between the technological and the industrial development, almost all the economic and financial activities based directly on it and any revolution coexists with the electric energy's rising demand [1-4]. Electrical, other energy types' a transformation output, highlights the main energy's significance. A power facility can be identified as the relationship, the power conversion/generation's facilities' physical form, to a certain type (e.g. electrical, heat), the distribution systems, the storage facilities, and the transmission facilities, that work as a definite facility. The demand for electrical is obtained global chiefly from the exploitation of conventional/fossil power resources, i.e. lignite/coal, petroleum and natural gas in a percent of approximately 75%. Lately, the utilize of sustainable power resources, more environmental biofuels and more efficient industries (e.g., cogeneration, the trigeneration) for electrical production is rising, chiefly due the petroleum-based fuel reserves' depletion, environmental pollution and the geopolitical reasons [3-5]. The rising need for electrical energy is linked to previously present obtaining options of the fossil-based fuels' future. Therefore, the requirement for alters in energy planning and policy and in the energy generation systems' design is emphasized. Regardless of the apparent advantages, the irrational operation and power resources brings' use to surface numerous troubles. The ecological damage reasoned by anthropogenic originating in human activities has reasoned several significant environmental troubles, such as the acidification, global climate change, and ozone layer depletion. In the higher atmosphere layers, the global climate change originates from the greenhouse gases' concentration rise [4-6]. The greenhouse gases emissions, in addition to other negative environmental pollutant, have chiefly anthropogenic source. Specially, the CO2 emission originates at its ultimate extent from the transports industry and in the use, exploitation, and production of fossil sources, e.g. for electrical production. Therewithal deforestation in worldwide norm outcomes in the CO2 determination capability's diminish via the photosynthesis process and thus in the CO2 concentration's rise in the atmosphere [4, 6]. Electricity's generation is a greenhouse gas emission manufacturing process as shown in the paper of which is detrimental to the ecology [7-9].

Researches have displayed that the energy industry supports to the total C emissions' approximately 40%. [10]. In climatic change, these gases manufactured in big quantity, cause a dominant impact [11]. The effect is considerably negative on socio-economic and natural systems. Lastly, long ignored, global warming, is at the forefront in the numerous countries' policies' development. In this context, it is essential to promote and develop renewable power resources that can give rise to sustainable plants [12-14].

The different methods have been used for investigation of ecological effects, while LCA (Life Cycle Assessment) is the most commonly applied methodologies' one. LCA is a cradle-to-grave reach, which has been considered as a precious ecological evaluation equipment for the chemical sectors [6-7]. In the most of the researches, the searchers have concentrated on acidification potential, greenhouse gas emissions, eutrophication potential to evaluate the electrical generation systems' ecological effects [15-17]. In Kazakhstan, Ahmad et al. analyzed to nuclear and renewable energy sources for electricity generation by multi-criteria evaluation [18]. In Tunisia, Brand and Missaoui assessed to the electrical production diverse mix scenarios by multi-criteria Analysis [19]. By Streimikien et al., the quantitative and qualitative criteria' analysis applied to ratio the electrical production industries considering their technological, economic, environmental, political, and social directions and sort them by priority order [20].

In Taiwan, Shen et al. assessed to the six sustainable technologies for electricity generation in according to environment, economy, and energy [21]. By fuzzy AHP, Susilawati and Tasri selected to the most suitable sustainable power sources for electrical production in Indonesia. This paper utilized from environmental criterion as one of the criteria for choice [22]. Zlatar et al. improved 6 metrics in 3 dimensions with the inclusion of security of energy system reliability, primary power supply, and environmental performances for instance [23].

This paper is presented to determine the eco-friendliest of electricity generation systems in terms of environmental effects. For environmental investigation, these conclusions show an important step of an electricity generation facility' global environmental evaluation. Moreover, the conclusions could be utilized to decrease the many running electrical generation systems' effects all over the world.

2. The Model Structure

To obtain a framework for relations with multi criteria decision-making issues, a hierarchical model is structured. Among decision levels, the model adopts a unidirectional hierarchical connection among the criteria. The selected methodology permits the hierarchical tree building and weighing each indicator through pairwise comparison between indicators and criteria by a matrix to obtain a coherent and consistent administration of both qualitative and quantitative data. To determine weights of criteria, such a method is used in this paper.

In the hierarchy for determining the ecological impact of electricity generation technologies, the aim of this research would be determining the most environment friendly technology based on a set of factors. These factors are air pollutants, greenhouse gas emissions (GHG), water use impacts, extraction, and waste. Fifteen different electricity generation options are compared from the perspective of each factors mentioned. The hierarchy composed of these factors is constructed as shown in Table 1 below:

Table 1. List of Factors

Factors				
Air Pollutants	Greenhouse gas emission	Water use impacts	Extraction	Waste

While measurements for some criteria are readily available, some others can only be estimated with respect to other variables. As it is the case in all multi-criteria decision making methods, the relative priorities of such criteria need to be determined. This is accomplished by pairwise comparison of the factors, starting with the main criteria. Below are the resulting properties shown in Figure 1.

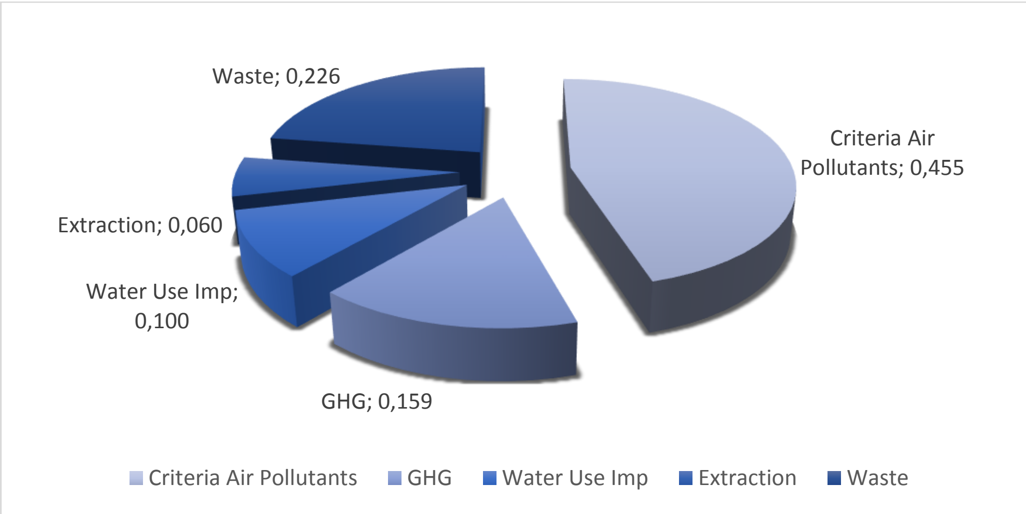


Figure 1. Priorities of factors

After determining the priorities of the factors with respect to the overall goal, electricity generation technologies are compared two by two with respect to each factor. 15 different technologies are used for the purpose of this investigation to be evaluated.

The environmental properties of the selected technologies are presented in Table 2 [24]. With regard to their life-cycle environmental effects, Table 2 supplies the diverse electricity production alternatives' a qualitative comparison. In order to use the data provided in the table, they need to be transformed into quantitative form. Thus, the available data is scaled from 1 to 5 based on their impact on ecological consequences.

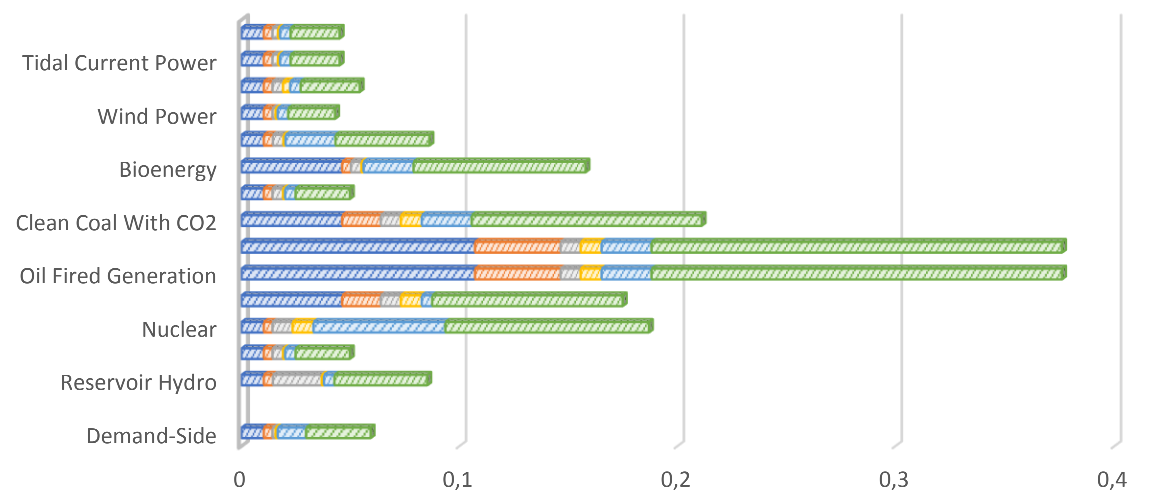
The final step in applying the technique is pairwise comparisons of the options with respect to each factor. In order to design an objective scheme for this purpose, the minimum and maximum values of the alternatives for each factor is determined. This range is divided into nine even ranges on a scale from 1 to 9. Finally, each technology alternative is placed in one of these ranges based on their values to compare them with each other.

Table 2. Environmental properties

Technology	Criteria Air Pollutants	GHG	Water Use Impacts	Extraction	Waste
Demand-Side Management	none	none	none	no	disposal of replaced equipment
Reservoir Hydro	none	low	flow pattern changed	no	no
Run-of-River Hydro	none	none	minimal	no	no
Nuclear Gas	none	none	thermal discharge	yes	radioactive
Natural Gas	low	medium	thermal discharge	yes	no
Oil-fired Generation	high	high	thermal discharge	yes	yes
Conventional Coal	high	high	thermal discharge	yes	yes
Clean Coal With CO_2	low	medium	thermal discharge	yes	yes
Energy Recovery Generation	none	none	low	no	no
Bioenergy	low	none	low	no	yes
Geothermal Power	none	low	low	no	yes
Wind Power	none	none	none	no	no
Solar PV	none	none	low	for manuf. only	no
Tidal Current Power	none	none	none consumptive	no	no
Wave Power	none	none	none consumptive	no	no

3. Results and Discussions

Based on the calculations above, the relative priorities corresponding to the ecological impact of each technology about all factors are presented below in Figure 3:



	Demand-Side	Management	Reservoir Hydro	Run-Of-River Hydro	Nuclear	Natural Gas	Oil Fired Generation	Conventional Coal	Clean Coal With CO2	Energy Recovery Generation	Bioenergy	Geothermal Power	Wind Power	Solar PV	Tidal Current Power	Wave Power
Criteria Air Pollutants	0,0102		0,0102	0,0102	0,0102	0,0462	0,1071	0,1071	0,0462	0,0102	0,0462	0,0102	0,0102	0,0102	0,0102	0,0102
GHG	0,004		0,0042	0,004	0,004	0,0177	0,0393	0,0393	0,0177	0,004	0,004	0,0042	0,004	0,004	0,004	0,004
Water Use Impact	0,0014		0,0224	0,0048	0,0092	0,0092	0,0092	0,0092	0,0092	0,0048	0,0048	0,0048	0,0014	0,0048	0,0025	0,0025
Extraction	0,001		0,001	0,001	0,0096	0,0096	0,0096	0,0096	0,0096	0,001	0,001	0,001	0,001	0,0033	0,001	0,001
Waste	0,013		0,0048	0,0048	0,0605	0,0048	0,0229	0,0229	0,0229	0,0048	0,0229	0,0229	0,0048	0,0048	0,0048	0,0048
Total	0,0296		0,0426	0,0249	0,0934	0,0874	0,188	0,188	0,1055	0,0249	0,0789	0,0431	0,0215	0,0271	0,0225	0,0225

Figure 3. Electricity Generation Technologies

The obtained results indicate that the Conventional Coal and Oil Fired Generation are the two technologies with the highest environmental impact with a global priority of 0.1880. On the other hand, Wind Power is the eco-friendliest technology with the lowest total impact value of 0.0215 based on the factors taken into account. Tidal Current Power and Wave Power follow the wind power with a slight difference. Figure 4 provides a visual comparison of the alternatives.

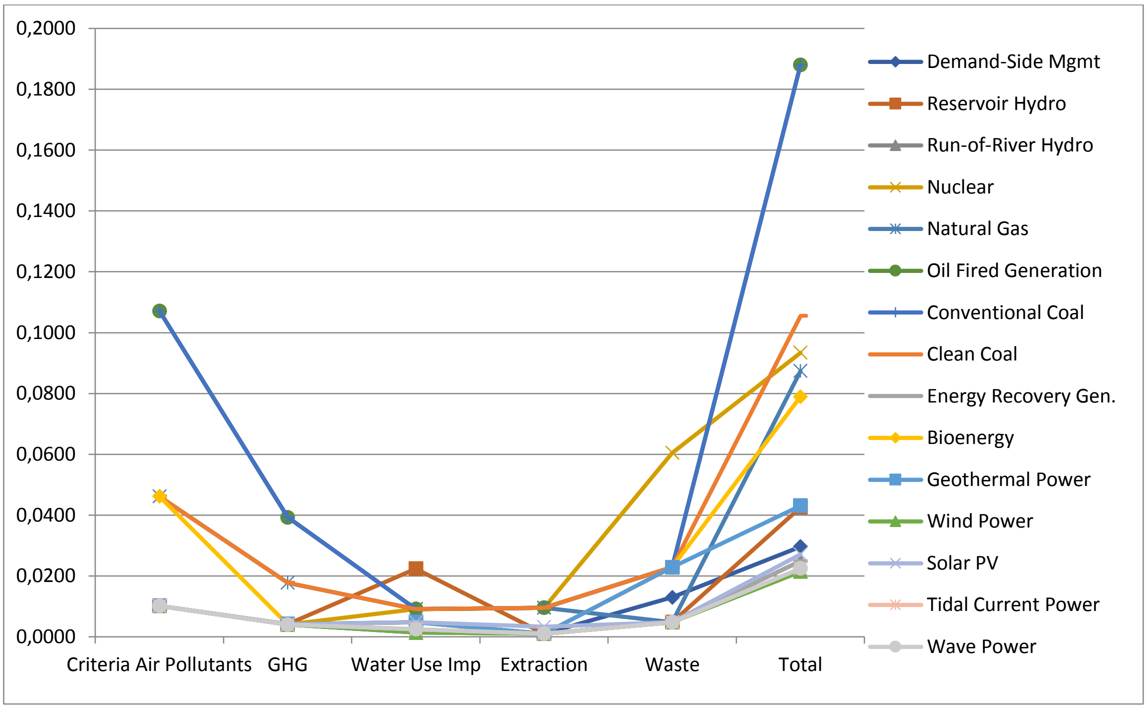


Figure 4. Comparison of electricity generation technologies

4. Conclusions

This paper aims to research the ecological effect of the electricity generation technologies based on various factors. These factors cover a wide range of potential ecological impact categories. The list of factors is evaluated and each factor is appointed a relative priority based on expert evaluations. Finally, the solution method is applied to the resulting scheme.

Each of the electricity generation technology's ecological effect are calculated for all of the factors involved. Based on the calculations, the eco-friendliest and the most environmentally damage technologies are determined.

Aside from providing a quantitative method to evaluate the alternative technologies, this study brings together a range of qualitative factors and quantify them based on expert opinions from the field. Although there are studies in the literature that involves environmental footprint anaysis, the extent of this research in terms of variety of the variables used, is beyond previous work done in this field.

The model used within the scope of this study can further be enhanced or improved to cover different aspects of technologies for the energy industry and serve both the policy-makers and the industry itself. The number and the variety of the selected factors can be further increased and their priorities can be adjusted accordingly. In this sense, the developed method is a robust approach to the problem.

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