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COMPARATIVE ASSESSMENT OF THE SUSTAINABILITY OF NUCLEAR AND COAL-FIRED POWER PLANTS

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ABSTRACT

The sustainable energy source is the key to the socio-economic development and cleaner environment of any country. Especially the sustainability of a baseload plant is more important as it generates most of the electricity. Coal and nuclear are the two main sources of energy for baseload plants now a day for many countries. The concentration of the study was to analyze and compare the sustainability of various aspects of coal-fired power plants and nuclear power plants. The main points which were discussed involved technology, safety and sustainability, and economy included environmental aspect, fuel availability, safety, risk, *etc.* The methodology was to collect data from various sources and analyzed it by using the analytic hierarchy process to draw a conclusion regarding the use of both energy technologies in the future. It has been seen that in most cases nuclear was more sustainable than coal power plant under this study.

Keywords: AHP; sustainability; safety; sensitivity analysis, coal, nuclear.

1. INTRODUCTION

Baseload power plants are the backbone of the electricity generation system in any country because of its large-scale production with high efficiency and cost-effectiveness. Baseload plants are used to supply electricity continuously from a specific power plant in order to reach the demand over a long period of time. Because of these, the sustainability of baseload plants is more important than other peak load plants. There are several choices of efficient baseload plants including coal, nuclear and hydroelectric plants. But the hydroelectric plants are not available everywhere due to geographical conditions, so the coal and nuclear power plants are the two best suitable candidates as a baseload plant for many countries. The analysis of sustainability that ensures to fulfill the present requirement without challenging the future generation requirement is conducted on both the nuclear and coal power plant for their pragmatic implementation in any country by using multi-criteria analysis. The Analytical Hierarchy Process (AHP) is used for this study. Sustainability of a baseload power plant contributes to socio-economic development and the advancement of the peoples living standard and to find a viable solution for the depleted resource. Sustainability is related to several criteria. The selection and weighting factors of the sustainability criteria are decided carefully to find optimum assessment between coal and nuclear power plant. The term sustainability in this context is taken from the definition of the United Nations Brundtland relating to various fields (Brundtland 1987).

The ground of sustainable development comprises from claiming three components: economy, society, and environment (Chatzimouratidis and Pilavachi 2008). While environment-friendly and safety are the major concern against negative impacts such as unexamined health and environment loss and CO_2 emission (Söderholm and Sundqvist 2003; Sundqvist 2004). Global warming is taken with sincere inspection and furthermore, international agreements and protocols are registered to restrain the multiplication of greenhouse gases (European Community (EESD Programed). Externalities of energy: extension of accounting framework and policy applications (technical report). 2005; Bond *et al.* 2006; Ottinger *et al.* 1990; San Martin 1989; Zwaan and Gerlagh 2006). In addition, to our knowledge, the work on the technological, economic and sustainability assessment have been done for power plants using the analytical hierarchy process (Chatzimouratidis and Pilavachi 2009). But the sensitivity analysis and consistency ratio was not taken into account for this type of analysis. Because of the ambiguity of weight of several criteria and subcriteria, sensitivity analysis and consistency ratio can change the prediction in different socio-economic conditions. For those reasons, the analysis of consistency ration and sensitivity along with AHP are the main objective of this paper. AHP is multi-attribute decision-making (MADM) method introduced and promoted by Saaty (Saaty 1980, 1990; Kablan 2004). The AHP is a decisive tool that is used to encounter the complex problem and to get a solution of the end node subcriteria for scoring according to the priority. And finally, the weight of the result indicated the overall assessment of the power plants. In this method, a hierarchy tree is needed to formulate for declaring criteria and subcriteria in accordance to their merit. The estimation process of criteria weights and scoring of power plants depends on true data. On the other hand, when the true data is unavailable then pairwise comparisons can be considered for the analysis of the subcriteria of technology, safety and sustainability and economy. Yet, the data can be altered due to the fact that it is relating to the number of parameters for the advancement of new technologies as well as innovations.

In this paper, technological, safety and sustainability, and economy features are mentioned for two types of power plants which are coal and nuclear. Where those criteria along with their subcriteria are designated to figure out the evaluation process and to

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enumerate a better power plant between the two alternatives.

2. HIERARCHY ANALYSIS

A hierarchy tree is demonstrated in Figure-1. The prime goal is to find out the optimum solution of the preferable power plant with respect to their main criteria along with subcriteria. The evaluation of a power plant is presented by level 1 which is at the top. Then, three main criteria illustrated by level 2 of this hierarchy. Those criteria are technology, safety and sustainability, and economy. These main criteria are further branched into various subcriteria.

Firstly, the technology criterion is classified into five subcriteria. These are efficiency coefficient, energy production, waste generation, capacity, and environmental aspect. Similarly, the criterion of economy is divided into four subcriteria, which are capital costs, operation & maintenance (O&M) costs, fuel costs, and external costs. Lastly, safety and sustainability have four subcriteria which include availability, reserve to production, environment and health issue and accident analysis. The above-mentioned subcriteria are discussed in the following sections briefly. In the hierarchy tree, level three is denoted for the subcriteria of the criteria of the technology, safety and sustainability, and economy. The only subcriterion which is operation and maintenance cost is further divided into fixed and variable costs. Those are signed in level 4. The last level of the hierarchy tree comprises of the alternatives which in this case are coal and nuclear power plant. The goal of this study is to find out the more sustainable by considering those subcriteria.

In a typical hierarchy tree, alternatives are connected with the subcriteria. In order to maintain simplicity, these lines have been discarded.

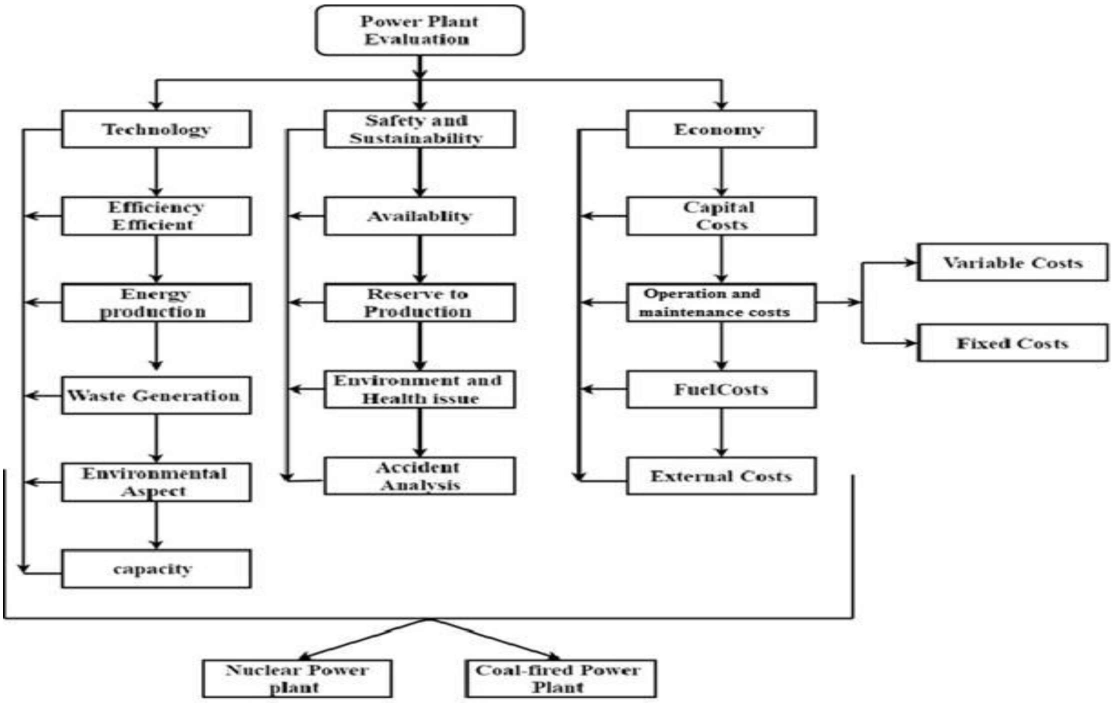

Figure-1. The hierarchy tree for optimization of technology, safety and sustainability, and economy criteria of the nuclear and coal-fired power plant.

2.1 Technology

2.1.1 Efficiency coefficient

The efficiency coefficient is defined as the ratio of the percentage of energy output to input energy. Efficiency which is relating to the useful energy harness from the energy sources can be improved by high plant reliability for the economic benefit (Beér 2007).

No machines are 100% efficient. So, Energy will be the loss in the form of heat in the generation of electricity. The heat rate is used to calculate the efficiency of a power plant. The power plant uses fuel energy to get heat and electricity. To calculate the efficiency of a power plant, the heat rate must be inversely multiplied with the 3412Btu (Administration 2018).

Table-1. Average efficiency coefficient for the two types of power plants (Administration 2007-2016).

Type of plant	Heat rate	Efficiency = (3412/Heat rate) ×100
Nuclear	10459	32.62262167
Coal	10493	32.51691604

2.1.2 Energy production

For the case of energy production, it is seen that nuclear fuel is much more preferable than the fuel of coal. Because one kilogram of Uranium (U) can produce the same amount of energy that can be produced by burning 4500 tonnes of high-grade coal that is why nuclear energy is beneficial for not only low-cost energy but also easier transport for a lot inventories to the facility. Despite both nuclear and coal fuel have high energy density but the magnitude of nuclear is higher. Such as nuclear has the average value of energy production per ton of nuclear fuel which is 2.0 x 109 kWh/t whereas the average thermal energy of coal is 6150kWh/t (Gabbard 1993).

Table-2. Average Energy production in kwh per kg fuel burn for the two types of power plants.

Type of plant	Energy production in kwh per kg fuel burn
Nuclear	20,000,000 kWh
Coal	6.15kWh

2.1.3 Waste generation

Electricity generation is a system that is a prime concern for modern civilization. To generate electricity, this has a subsequent negative impact on the environment by increasing population solid, liquid and gaseous waste. These wastes can be classified as emission wastes and non-emission wastes. By the basis of the mentioned point, fuel wastes come out from fuel, conversion facility, construction facility, materials manufacture. And non-fuel wastes are found from transportation, maintenance wastes, spillage and clean-up, and final decommissioning wastes. In the treatment processes of extracted fuel and also raw material from mining to drilling, the large amount of wastes is generated both coal and nuclear fuel. On the one hand, the amount of waste for coal mining is on the order of 600-1200 thousand T/ GW (e) and the other hand, the nuclear fuel chain amount the uranium or thorium is typically present in 100 thousand tonnes of tailings per GW (e) (Ellis and Peake 1995).

A classical coal-fired power plant capacity of 1000MWe during its 30 years' service lifetime consumes 60 million tonnes of coal. It propagates around 15 million tonnes of ash which contains toxic metals and gaseous substances. In comparison, a 1000MWe nuclear power plant in its fuel cycle produces solid high-level waste of 2 cubic meters and solid low-level waste of 23,0000 cubic meters in one year. Nuclear wastes are under control of their special waste repositories. High-level wastes are needed to cool down for fifty years. Afterward, they are separated as a reprocessed fuel which is 3% of the total high-level waste. Finally, this waste can be disposed to a deep geological repository. In the repositories, Intermediate- and low-level wastes are dumped off near to the surface.

Table-3. Average waste generation for the two types of power plants (Rashad and Hammad 2000).

Type of plant	Waste generation
Nuclear	25t (high),310t (intermediate),460t (low)
Coal	6.5Mton (CO_2),900t SO_2,4500t NO_x,320,000t Ash

2.1.4 Capacity

The capacity which is the most vital parameter of a power plant is a dimensionless ratio. Capacity is the actual quantity of electricity generated over a period of time to the maximum quantity of electricity that could be generated by running at full power over that same period of time. The capacity factor for the two alternatives has distinct features where the one indicates to time and the other one mentions to the quantity of electricity. It is a very important factor for the overall evaluation. The capacity cannot calculate with 100% accuracy because of equipment and component out of service or failures and schedule maintenance.

The example of the base power plant which has the ability to produce electricity continuously with high output and efficiency at a lower cost is nuclear, coal and biomass plants. And these power plants burn solid fuel in their operation life of power production. Among the baseload power plant, the nuclear power plant has the highest capacity factor.

Table-4. Average capacities of nuclear and coal power plants (IAEA (2002).

Type of plant	Capacity
Nuclear	90.5
Coal	70.8

2.1.5 Environment aspects

Although the environment has been affected by so many parameters, the considerable parameters involving this investigation are mining, ash and heavy metal and GHG issues. Coal mining releases metals into the soil and environment and has an impact on deforestation. Those effects stay even a long time after removing the coal. Whereas Uranium mining has the potential to affect surface water and groundwater quality, air quality and health risk of mineworkers. A 1000MW coal power plant produces 320000 tonnes of ash annually. Coal mining is also the reason for spreading heavy metals of arsenic, cobalt, nickel, lead, mercury, cadmium, and vanadium approximately 400 tonnes (IAEA, 1997](Pirelli 1986). GHG emission factors that are high have a range of scale from 500g to 1200g CO_2 equiv./KW(e). So, it is required to improve energy efficiency in the near future by keeping the lower GHG effects.

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Table-5. Mass of emissions in kg from Coal and Nuclear Technologies from 100 Years of Operation (Dontala, Reddy, and Vadde 2015).

Types of plants	CO2(kg)	CO(kg)	CH4(kg)	NOx(kg)	SO (kg)
Coal	24,428,587	6090	97989	25020	26217
Nuclear	380,836	582	1296	1052	2506

2.2 Safety and Sustainability

2.2.1 Availability

For a power plant, the term availability is described as the measure of the time span that it can deliver electricity over a specific period, divided by the quantity of time in that period. A power plant can be in a shutdown condition in accordance with maintenance, repairs, refueling, and, wind and the scarcity of sunlight(Persaud, Flynn, and Fox 1999). Availability depends on a lot of parameters which are the standard of the equipment, its maintenance, the kind of fuel and the outline of the plant which is why availability plays a significant role in the power plant. Coal and nuclear power plants have the magnitude of availabilities between 80% and 96% respectively. Most of the recent power plants tend to have greater accessibility. So, the requirement of the preventive maintenance of a power plant is very crucial as enhancements in design and technology.

Table-6. The availabilities for the two types of power plants (International Atomic Energy Agency (IAEA), 2002).

Type of plant	Availability
Nuclear	96
Coal	85.4

2.2.2 Reserve to production ratio (RPR)

This ratio is one of the most important parameters to know about the size of the natural resource. The value of reserve to production ratio refers that the number of years of present reserves contributes to electricity if their rate of use is known. The value of this ratio alters as the size of the reserve changes when a new ore is discovered of any type of fuel. This reserve to production ratio is generally expressed with respect to years. This can also predict the availability of the resource for the future generation.

These R/P ratios are the most essential when it is considered to analyzing fossil fuels, hence it is calculated by the equation (1) as;

$$\text{RPR}=\frac{amount\ of\ known\ resource}{amount\ used\ per\ year} \tag{1}$$

Here, non-economic extraction is not considered for this factor.

Table-7. The approximate average RPR ratio for the Coal-fired and Nuclear power plant (World Energy Resources 2013).

Type of power plant	RPR (years)	Estimated reserves
Coal	Over 100 (164≤)	891 billion tones
Nuclear	Over 100	N/A*

2.2.3 Environment and health issue

The fatalities of the nuclear power plant are significantly lower compare to the coal power plant. The nuclear power plant has a concern on providing higher safety issues to get protection from the radiation hazard. So, there are rules associated with the radiation dose that would be absorbed by the employee of the nuclear facility. On the other hand, the average life expectancy of the employee of coal mining is greatly shorter than the normal level of life expectancies for its health risk.

Table-8. The number of fatalities for the two types of power plants.

Type of plant	Number of fatalities
Nuclear	31
Coal	6418

2.2.4 Accident analysis

Although the precaution of the safety of nuclear power is the topmost priority the serious accident of the nuclear reactors happened in Three Mile Island (TMI), Chernobyl and Fukushima.

The NRC, DOE, EPA and the department of health investigated the radiological consequences. From the examination, it was found that the 2 million people had received radiation dose an average one millirem dose which was higher the background dose in the case of TMI accident. The maximum dose was deposited to those people at the close the site region. The amount of dose was not greater than 100 millirem from the background probably (Commission 2013).

The short-term fatalities of the nuclear power plant have a value of 0.01 the average fatalities for 1GWe energy production in one year. On the contrary, the generation of electricity from coal power plants results in more casualties which have a value of 0.32 the average fatalities for 1GWe energy production in one year (Rashad and Hammad 2000).

Japan was experienced by an earthquake of a strong magnitude of 9 (Richter scale). That was caused by

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about 15 meters tsunami and subsequent shutdown of the nuclear power plants of Fukushima Daiichi. For this reason, it is necessary to check and double-check to design features and the site selection to ensure the appropriate safety for the commercial nuclear power plant against those possibilities of risk. Spent fuel pools that are needed to investigate further are initially stored place of spare parts of the reactor for reducing decay heat.

Table-9. Short-term fatalities for various energy technologies (DEVELOPMENT 2010).

Types of plants Short term fatalities	Fatalities Range	Fatalities Total/TWy
Coal	5-434	6418
Nuclear	31	31

2.3 Economy

A prime concern for the power plant is to get the electricity with minimum cost as well as the quality of performance. Net cost per KWh is determined from the capital fixed cost (FC), costs relating to operation and maintenance (O&M) and cost associating with fuel and external. A basic formula can be applied for calculating the annual cost of a power plant.

Annual Cost(Ct), $Ct=(I+D+T)/100Cc+(W+R+M)+ Cf$ (2)

Where I is the interest, D is depreciation. T is tax and insurance, (%) Cc is the construction cost, W is wage and salaries, R is repairs, M is miscellaneous; Cf the fuel cost.

2.3.1 Capital costs

Capital costs of a plant are associated with the costs of land, buildings, and equipment that are necessary for the operation. Where the labor costs and the maintenance costs of the equipment are not accounted in the capital costs. This cost is very high for both nuclear and coal power plants. Capital costs are calculated from the capacity of the power plant in the unit of (£/kW).

Table-10. The total capital costs for the nuclear and coal power plant ((IAEA, 2002).

Type of plant	Capital cost (€/kW)
Nuclear	1590
Coal	975

2.3.2 Operation and maintenance costs

Operation and maintenance costs incorporate costs relating to the representatives, the assets spent on the generation of electrical energy and the service of the power plant. The maintenance and suspension of the power plant operation are needed to enhance power plant lifetime and to prevent sudden failure. The maintenance costs are not so much high as failure costs. And this has an impact on not only increment of the validity of a plant but also the index factor of a plant.

The costs of O&M are separated by two subcategories, specifically costs relating to fixed O&M and costs connecting with the variable O&M. The fixed costs of O&M costs are those expenses that are aligned with operation as well as maintenance of the power plant each year when the power plant is not in the mode of electricity generation. On the other hand, the variable O&M costs are specifically related to the mode of electricity generation of the power plant. In this paper, two sorts of costs are assessed and exhibited independently.

Table-11. The average amount for fixed and variable O&M costs for the coal and nuclear power plant (IAEA, 2002).

Type of power plant	Fixed operation and maintenance costs (cents/kWyr)	Variable operation and Maintenance costs (cents/kWh)
Coal	19	0.183
Nuclear	30	0.033

2.3.3 Fuel costs

Fuel is the most vital material for discharging energy. Fuel can discharge its energy either by a chemical process that is burning, a nuclear process that is directly related to the nuclear fission reaction or the nuclear fusion reaction. It is an essential property of a fuel that is the energy of the fuel can be accumulated or to be discharged just when it requires. The discharge is performed in a controlled way so that this energy can utilize to get the necessary work. Fuel costs are related to raw material (which is essential for power plant operation), mining, transportation, and processing of fuel. Comprehensive assessment of non-radioactive emissions both subjective and objective ways is scrutinized (Chatzimouratidis and Pilavachi 2007).

The costs relating to the fuel may alter extensively in various time periods for a few reasons. The probabilistic analysis of fuel costs is needed to forecast the situation (Feretic and Tomsic 2005). An extensive analysis is done in Finland to reach the desired performance of a power plant and to get the data of cost for the power plant regarding the baseload (Rissanen and Sauli 2000). Table-12 introduces the normal fuel costs for two sorts of energy plants (US DOE/EIA, 2005).

Table-12. Average fuel costs for the two types of power plants ((USDOE/EIA), 2005).

Type of plant	Fuel costs (cents/kWh)
Nuclear	0.27
Coal	1.31

2.3.4 External costs

Those costs are characterized by the cost of health and the environment. However, it is not incorporated with the cost of the generation of electricity. This external cost is related to the restoration of the negative side effects that happen on human health as well as the ecosystem during the operation power plant. In order to restore the quality life of the people which had degraded, the external cost is evaluated based on the life cycle of the power plants (OECD, 2003).

The external cost is calculated by a few models in the sector of power generation. For this reason, it arises competition between non- fossil and fossil power plants where the control of emission should be better as much as possible (Klaassen and Riahi 2007; Rafaj and Kypreos 2007). It should be pointed out that, under this definition, ecological contamination would not be fitted into the external costs if the individuals who experience the negative impact of that contamination were completely adjusted (Virdis 2001). Table-13 presents the external costs of the two types of power plants.

Table-13. The external costs for coal and nuclear power plant (DEVELOPMENT 2013).

Type of plant	External costs (cents/kWh)
Nuclear	0.49
Coal	8.30

3. Analysis by Weight Criteria

To compare the criteria by using the Analytic Hierarchy Process (AHP), the measurement scale of Table-14 is followed. For instance, if two elements X and Y are being compared by using the AHP measurement scale, their relative importance can be considered either numerically or based on experience.

Suppose, it is being considered that, under a certain benchmark X is moderately important than Y, then the section of row X and column Y is filled with number 3 or the phrase ‘‘moderately important”.

Table-14. AHP measurement scale.

Scale	Degree of preference	Meaning (X compared to Y)
1	Equal importance	X is equally important to Y
3	Moderate importance of one factor over another	X is moderately important than Y
5	Strong or essential importance	X is strongly important over Y
7	**Very strong importance**	**X is very strongly important than Y**
9	Extreme importance	X is extremely important than Y
2,4,6,8	Values for inverse comparison	Here Y is considered as the prior value over X

The power plant evaluation criteria demonstrated in Figure-1. Three main criteria are technology, safety and sustainability, and economy which are considered as equally important, while the pairwise comparison is executed among the sub-criteria of technology, safety, and sustainability as well as economy. The decision has to make between two subcriteria to Figure out which one is more essential than the other within a certain limit.

Table-15 shows the significance of those subcriteria of technology which is one of the equally important factors among the three factors of power plant evaluation. Pairwise comparison is done by using the AHP measurement scale that is presented in Table-14.

Table-15. Pairwise comparison among power plant “Technology” subcriteria.

Subcriteria of technology	Efficiency coefficient	Energy production	Waste generation	Capacity	Environmental Aspect
Efficiency coefficient	1	1/5	1/7	1/3	1/9
Energy production	5	1	1/3	3	1/5
Waste generation	7	3	1	5	1/3
Capacity	3	1/3	1/5	1	1/7
Environmental Aspect	9	5	3	7	1

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Tables 16 and 17 show the significance of those subcriteria of safety and sustainability, and economy respectively whereas pairwise comparison is done by using the AHP measurement scale which is showed in Table-14.

Table-16. Pairwise comparison between power plant "Safety and sustainability" subcriteria.

Subcriteria of technology	Availability	Reserve to production ration	Environment and Health Issue	Accidental Analysis
Availability	1	1/5	1/3	1
Reserve to production ratio	5	1	3	5
Environment and Health Issue	3	1/3	1	3
Accidental Analysis	1	1/5	1/3	1

Table-17. Pairwise comparison among power plant "Economic" subcriteria.

Subcriteria of technology	Capital Costs	Operation Management Costs	Fuel Costs	External Costs
Capital Costs	1	5	1	3
Operation Management Costs	1/5	1	1/5	1/3
Fuel Costs	1	5	1	3
External Costs	1/3	3	1/3	1

Among all the subcriteria of the power plant evaluation factor 'Economy', only one subcriteria ' O& M cost' has further divided into two parts which are 'variable cost' and 'fixed cost' because of the importance of these cost to the power plant economy. Table-18 shows the importance of subcriteria where the pairwise comparison is done by using AHP. whereas variable O&M costs are strongly more important than fixed O&M costs.

Table-18. Pairwise comparison between fixed and variable O&M costs. `

Subcriteria of O&M costs	Fixed O&M costs	Variable O&M costs
Fixed O&M costs	1	1/5
Variable O&M costs	5	1

3.1 Calculation of the Consistency Ratio and Sensitivity

After putting the numerical value of the criteria in the pairwise comparison by means of AHP, the analysis of the consistency is required to strengthen the judgment. Since that numerical values are to appraise among the individuals by the basis of subjective preferences, that is why it is necessary to have acceptability of the inconsistency limit. For this reason, AHP computes a consistency ratio (CR) where the comparison of the consistency index (CI) of the defined matrix and the random index (RI) relating with sample size is done to get a better solution of the complex problem (Mu and Pereyra-Rojas 2017). This consistency ratio (CR) is tolerable when it is equal to or less than 0.10 (Saaty 1990).

At first, a priority matrix is formed from the pairwise evaluation among the subcriteria. Then the priority matrix is multiplied with the priority vector which is based on the criteria weight of the related factors by using the matrix multiplication process to get the augmented matrix. Afterward, the maximum average value of the eigenvector (λmax) is computed.

Consistency index is calculated by

$$CI = \frac{(\lambda\text{max} - \text{n})}{(n-1)} \tag{3}$$

Where n is the sample size or the number of the compared element.

And Consistency ratio is computed by

$$CR = \frac{CI}{RI} \tag{4}$$

Overall priorities depend on the weight of the criteria. It is necessary to understand the results if the criteria weight is changed. This process is called sensitivity analysis. This analysis helps to realize how strong the original decision and the quantity of deviation from the original decision (Mu and Pereyra-Rojas 2017). Sensitivity analysis is calculated for technology, safety and sustainability, and economy leading case.

In Table-19, pairwise comparison between two alternatives (coal & nuclear power plant) according to their importance is presented by using the AHP measurement scale which represents Table-14. Although this measured value is based on the AHP scale, while Table-1 is played an important role to take the decision by which value of the scale can be used to evaluate those

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alternatives of the efficiency coefficient. Whereas nuclear is equally important as coal. By using the AHP measurement scale, the pairwise comparison is also conducted for energy production sub-criteria of coal & nuclear power plant while Table-2 is played a key role to make the decision. Where nuclear is extremely more important than coal because of energy production per kg of fuel burn of nuclear is way higher than coal. A similar situation is also observed in the case of waste generation subcriteria while nuclear is extremely more important than coal by following Table-3. For the case of capacity subcriteria, nuclear is moderately more important than coal by observing Table-4. In the same way for the environment aspect subcriteria, nuclear is strongly more important than coal by observing Table-5.

Table-19. Pairwise comparison of efficiency coefficient between coal and nuclear power plant.

Efficiency coefficient	Coal	Nuclear
Coal	1	1
Nuclear	1	1

In Table-20, pairwise comparison of availability sub-criteria under the safety and sustainability criteria between two alternatives (coal & nuclear power plant) based on their significance is presented by using the AHP measurement which reflects the Table-14. The decision is based on Table 6 from where the value of the scale can be used to evaluate those alternatives. Where nuclear is moderately more important than coal. By using the measurement scale of Table-14, pairwise comparison of the reserve to production ratio between two alternatives (coal & nuclear power plant) is also done while Table-7 is also played a key role to make the decision. While nuclear is equally important than coal. For the case of environment and health issue subcriteria, nuclear is extremely more important than coal by observing Table-8. On account of environmental and health issues, nuclear is considered a higher priority than coal.

An analogous situation is also observed in the case of accidental analysis subcriteria while nuclear is extremely more important than coal by following Table-9.

Table-20. Pairwise comparison of availability between coal and nuclear power plant.

Availability	Coal	Nuclear
Coal	1	1/3
Nuclear	3	1

Pairwise comparison of capital cost between two alternatives (coal & nuclear power plant) based on their significance is presented by using the AHP measurement scale. In this case, Table 10 is played the central role to take the decision by which the value of the scale can be used to evaluate those alternatives. In this case, coal is more important than nuclear. By using the same measurement scale, pairwise comparison of operation management costs subcriteria is executed while Table-11 is considered to make the decision. Where coal is more important than nuclear. For the case of fuel costs subcriteria of coal & nuclear power plant, nuclear is strongly more important than coal by observing Table-12, because of high energy production from nuclear fuel. In the same way, it is observed from the external costs subcriteria for the two alternatives, nuclear is extremely more important than coal by following Table-13.

Table-21. Pairwise comparison of capital cost between coal and nuclear power plant.

Capital cost	Coal	Nuclear
Coal	1	3
Nuclear	1/3	1

Based on the AHP method, global criteria and subcriteria weights are illustrated in Table-22. Global criteria are related to the overall weights among the criteria. And it also reflects their significance and importance with respect to the entire goal. Global weights mainly give information about the weight of the three equally important criteria which are technology, safety and sustainability and economy. For this assessment, the subcriteria of those criteria also is calculated which is presented in Table-22.

Table-22. Global criteria and sub-criteria weights.

Power Plant Evaluation (100%)					
Technology (33%)		**Safety and Sustainability (33%)**		**Economy (33%)**	
Efficiency coefficient	1.16%	Availability	3.22%	Capital Costs	12.92%
Energy production	4.47%	Reserve to production ratio	18.49%	Operation Management Costs	2.20%
Waste generation	8.86%	Environment and Health Issue	8.38%	Fuel Costs	12.92%
Capacity	2.26%	Accidental Analysis	3.22%	External Costs	5.92%
Environmental Aspect	16.76%				

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4. RESULTS AND DISCUSSIONS

In the result section, first, the consistency index (CI) is discussed to judge our decision making based on the pairwise comparison. After that, the global percentage weight of the end nodes with sensitivity is illustrated by a bar chart, where it is showing the evolution of various subcriteria for three sensitivity cases along with the calculated case. The last results are for end-node analysis for the two alternatives along with sensitivity to find out the more sustainable power plant. The Table-23 is showing the consistency index for the three main criteria.

Table-23. Result of the consistency index.

Criteria	Technology	Safety and Sustainability	Economy
Consistency Index (CI)	0.054641198	0.016480137	0.016621188

It is seen that all the values of the CI are less 0.1, so the judgment regarding technology, safety and sustainability, and economy subcriteria is consistent for all the criteria (Saaty 1990).

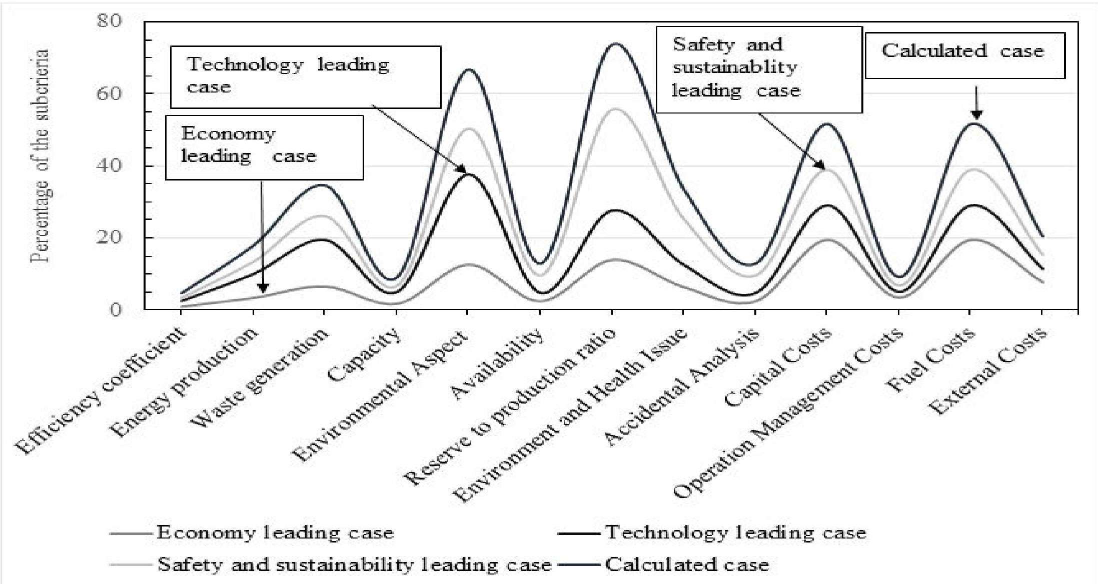

Figure-2. Global percentage weights of the end node criteria of the hierarchy tree with sensitivity analysis.

According to this assessment, the overall percentage of the weight of the subcriteria and sensitivity is demonstrated in Figure-2 and Table-22 with the detailed analysis of the subcriteria of the power plants. Where the data of the criteria of Table-22 is used as calculated criteria for Figure-2. The calculations are done for the four cases, out of which the first case is for the calculated case, where all the criteria weights are equally important. The other three cases for the sensitivity analysis, one criterion is lading among them. Such as, for the technology leading criteria, half of the total criteria weight (50%) is allocated for the technology and the rest 50% is equally divided for the other two criteria. A similar process is followed for the safety and sustainability leading case as well as the economy leading case.

The weight criteria for the calculated case, the magnitude of the reserve to production (r/p) ratio which is 18.31 % is certainly the dominating one compare to other subcriteria. The second most important subcriterion is the environmental aspect that is nearly two percent shorter than the r/p ratio. Then, the third-most leading subcriteria is not only the fuel cost but also the capital cost. Both have the same value which is 12.83% while energy production per kg of fuel burn is about 4% lower. The value of the environment and health issue is approximately close to the waste generation. External cost, energy production, and availability and all other subcriteria are following a decreasing trend shown in Figure-2.

The weight criteria for the technology leading case, environment aspect which is 25.14% is the dominating subcriterion whereas the reserve to production ratio which is 13.87% is the second most leading subcriterion. While waste generation is approximately close to the environment aspect. Other subcriteria with their descending order are fuel and capital cost whose value is equal to 12.83%, energy production which is 6.72%, environment and health issue which is 6.29% and so on.

The weight criterion for the safety and sustainability leading case; reserve to production ratio which is 27.74% is the dominating subcriterion where the environmental aspect which is 13.87% is the second most leading subcriterion. Other subcriteria with their descending order are environment and health issue which is 12.58% fuel and capital cost whose value is equal to 9.72%, energy production which is 6.72%, waste generation which is 6.5% and so on.

Weight criteria when the economy is the leading case, capital and fuel cost which are 19.44% are the dominating subcriteria where the reserve to production ratio which is 13.87% is the third most leading subcriteria. Other subcriteria with their descending order are environment aspect whose value is equal to 12.57%, external cost which is 7.67%, waste generation which is 6.5% and so on.

For the coal and nuclear power plant, end node analysis based on an analytical hierarchy process is done. From that analysis, their sustainability can also comprehend where the overall percentage of the sub-criteria are computed from their priorities.

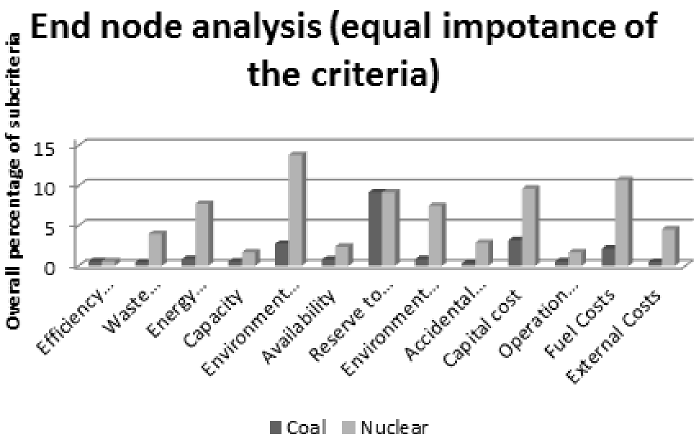

Figure-3(a). End node analysis for coal and nuclear power plant where all criteria are important.

For this analysis, all the subcriteria between coal and nuclear the power plant is considered equally important. Among those subcriteria, the environmental aspect is the most important one. In between coal and nuclear power plants, most of the criteria of the nuclear power plant such as environment aspect, environmental health issue, capital cost, fuel cost and so on are certainly higher except reserve to production ratio and efficiency coefficient where their magnitude is equal.

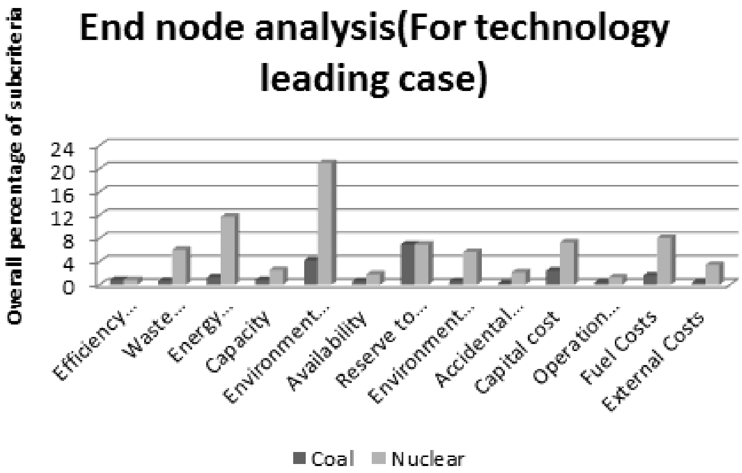

Figure-3(b). End node analysis for coal and nuclear power plant where technology is the leading criterion.

For this analysis, all the subcriteria of technology between coal and nuclear the power plant is considered more important than other subcriteria. Among those subcriteria, the environmental aspect is the most important one. In between nuclear and coal power plants, most of the criteria of the nuclear power plant such as environment aspect, environmental health issue, capital cost, fuel cost and so on are certainly higher except reserve to production ratio and efficiency coefficient where their magnitude is equal.

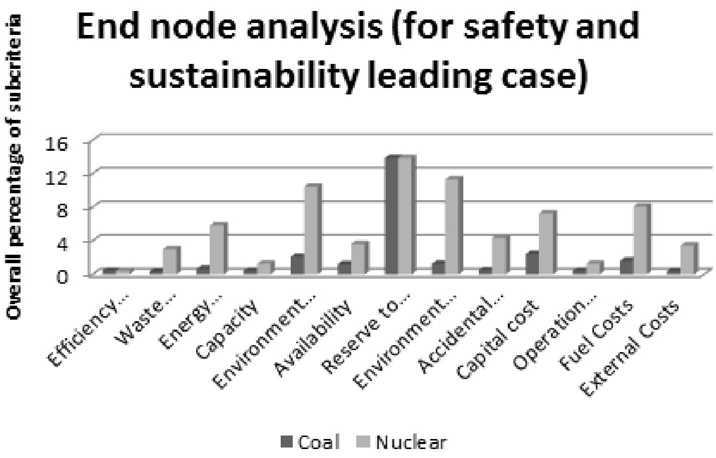

Figure-4(a). End node analysis for coal and nuclear power plant where safety and sustainability is leading criteria.

For this analysis, all the subcriteria of safety and sustainability between coal and nuclear the power plant is considered more important than the other subcriteria. Among those subcriteria, the reserve to production ratio is the most important one. In between nuclear and coal power plants, most of the criteria of the nuclear power plant such as environment aspect, environmental health issue, capital cost, fuel cost and so on are certainly higher except reserve to production ratio and efficiency coefficient where their magnitude is equal.

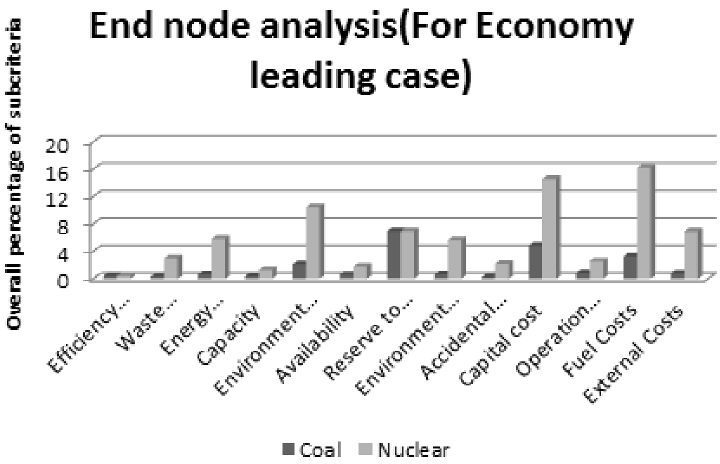

Figure-4(b). End node analysis for coal and nuclear power plant where economy is leading criteria.

For this analysis, all the subcriteria of economy between coal and nuclear the power plant is considered more important than the other subcriteria. Among those subcriteria, fuel cost is the most important one. in between nuclear and coal power plants, most of the criteria of the nuclear power plant such as environment aspect, environmental health issue, capital cost, fuel cost and so on are certainly higher except reserve to production ratio and efficiency coefficient where their magnitude is equal.

5. CONCLUSIONS

From the analysis between two power plants (coal and nuclear) with respect to subcriteria of technology, safety and sustainability, and economy by using the AHP, it has clearly appeared that the nuclear power plant is more sustainable than coal power plant whereas the consistency index testified the judgment among those subcriteria.

For the sensitivity analysis among the subcriteria of technology, safety and sustainability, and economy, the criteria weight of the reserve to production (r/p) ratio is

18.31 %. It is certainly the dominating one compare to other subcriteria. The same effect is also observed when it changes the three other leading cases. For the end node analysis between coal and nuclear power plant when all the criteria between coal and nuclear power plant is considered equally important, most of the subcriteria of nuclear power plant such as environment aspect, environment health issue, capital cost, fuel cost and so on are certainly higher except reserve to production ratio and efficiency coefficient where their magnitude is equal.

For the sensitivity of the end node analysis between these two power plants, all the cases between coal and nuclear, most of the subcriteria of the nuclear power show higher value than the subcriteria of the coal power plant.

REFERENCES

Administration, Energy Information. 2007-2016. Electricity for annual -Average Tested Heat Rates by Prime Mover and Energy Source, 2007-2016.

(Btu per Kilowatthour).

Repeated Author. 2018. tools at the frequently ask questions on What is the efficiency of different types of power plants?

Beér János M. 2007. High efficiency electric power generation: The environmental role. Progress in Energy and Combustion Science. 33(2): 107-134.

Bond Tami C, Birgit Wehner, Antje Plewka, Alfred Wiedensohler, Jost Heintzenberg and Robert J Charlson. 2006. Climate-relevant properties of primary particulate emissions from oil and natural gas combustion. Atmospheric Environment. 40(19): 3574-3587.

Brundtland Gro Harlem. 1987. Our common future (Report for the World commission on Environment and Development, United Nations). Our common future: report for the World Commission on Environment and Development, United Nations.

Chatzimouratidis Athanasios I and Petros A Pilavachi. 2007. Objective and subjective evaluation of power plants and their non-radioactive emissions using the analytic hierarchy process. Energy policy. 35(8): 4027-4038.

Repeated Author. 2008. Sensitivity analysis of the evaluation of power plants impact on the living standard using the analytic hierarchy process. Energy Conversion and Management. 49(12): 3599-3611.

Repeated Author. 2009. Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. Energy policy. 37(3): 778-787.

Commission, Nuclear Regulatory. 2013. Backgrounder on the Three Mile Island Accident.

Development, nuclear energy agency organisation for economic co-operation And. 2010. Comparing Nuclear Accident Risks with Those from Other Energy Sources.

Repeated Author. 2013. Nuclear Electricity Generation: What Are the External Costs?

Dontala Siva Prasad, T Byragi Reddy, and Ramesh Vadde. 2015. Environmental aspects and impacts its mitigation measures of corporate coal mining. Procedia Earth and Planetary Science. 11: 2-7.

Ellis J and S Peake. 1995. Policy options to limit c02 emissions from electricity supply An OECD perspective. ÔÎIS (Sil A: 93).

European Community (EESD Programed). Externalities of energy: extension of accounting framework and policy applications (technical report). 2005.

Feretic Danilo and Zeljko Tomsic. 2005. Probabilistic analysis of electrical energy costs comparing: production costs for gas, coal and nuclear power plants. Energy Policy. 33(1): b5-13.

Gabbard Alex. 1993. Coal combustion: nuclear resource or danger. Oak Ridge National Laboratory Review. 26(3&4).

Kablan MM. 2004. Decision support for energy conservation promotion:: an analytic hierarchy process approach. Energy policy. 32(10): 1151-1158.

Klaassen, Ger, and Keywan Riahi. 2007. Internalizing externalities of electricity generation: An analysis with MESSAGE-MACRO. Energy Policy. 35(2): 815-827.

Mu Enrique and Milagros Pereyra-Rojas. 2017. Practical Decision Making Using Super Decisions V3: An Introduction to the Analytic Hierarchy Process: Springer.

Ottinger Richard L, David Wooley, N Robinson, D Hodas and S Babb. 1990. Environmental costs of electricity.

Persaud Shashi, Damian Flynn and Brendan Fox. 1999. Potential for wind generation on the Guyana coastlands. Renewable Energy. 18(2): 175-189.

Pirelli, P. et al. 1986. The Environmental Impacts of Production and use of Energy Report Series, ERS - 17-96.

Rafaj, Peter, and Socrates Kypreos. 2007. Internalisation of external cost in the power generation sector: Analysis with Global Multi-regional MARKAL model. Energy Policy. 35(2): 828-843.

Rashad SM and FH Hammad. 2000. Nuclear power and the environment: comparative assessment of environmental and health impacts of electricity-generating systems. Applied Energy. 65(1-4): 211-229.

Rissanen, Risto Tarjanne, and Sauli. 2000. Nuclear Power: Least-Cost Option for Baseload Electricity in Finland.

Saaty, Thomas L. 1980. The analytic hierarchy process New York. Nachhaltigkeit im Einkauf von Logistikdienstleistungen. 137.

Repeated Author. 1990. Decision making for leaders: the analytic hierarchy process for decisions in a complex world: RWS publications.

Repeated Author. 1990. How to make a decision: the analytic hierarchy process. European journal of operational research. 48(1): 9-26.

San Martin, Robert L. 1989. Environmental emissions from energy technology systems: the total fuel cycle. Deputy Assistant Secretary for Renewable Energy, US Department of Energy, Washington, DC.

Söderholm Patrik and Thomas Sundqvist. 2003. Pricing environmental externalities in the power sector: ethical limits and implications for social choice. Ecological Economics. 46(3): 333-350.

Sundqvist Thomas. 2004. What causes the disparity of electricity externality estimates? Energy Policy. 32(15): 1753-1766.

Virdis Maria Rosa. 2001. Energy policy and externalities: the life cycle analysis approach. Externalities and Energy Policy: The Life Cycle Analysis Approach. 15: 195.

Zwaan Bob Van der and Reyer Gerlagh. 2006. Climate sensitivity uncertainty and the necessity to transform global energy supply. Energy (Oxford). 31(14): 2571-2587.