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Assessment of Power Generation Plant Performance by Energy Sources Rating Environmental Impact and Operating Cost

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ABSTRACT

High percentage of global electrical power production today comes from steam plants. Thus, improving performance of such plants is crucial to minimize its environmental effects and achieve operational economy. This project aim is to study several aspects of plants operation such as pollution, safety, health, economy and dangerous incidents during operation. Thereby, assessment may be conducted through specific rating factor as death rate (DR); greenhouse emissions (CO_2EQV); capacity factor (CF); generating efficiency (η); reliability (R_{bt}); cost; availability; global production (P_{rd}) & consumption rates (E_{cons}). These rating factors were applied to all types of energy sources to evaluate its safety & cleanliness (DR & CO_2EQV); reliability at maximum power at specific time (CF & R_{bt}); generation efficiency to maintain acceptable cost and power losses control (η & Cost); examining finally each source availability to insure continuous operation under regular global production (P_{rd}) & consumption rates (E_{cons}). As a result, the percentage contribution of each energy source showed that fossil fuels are the dirtiest & most dangerous, while both renewable and nuclear are safe & clean. As for DR factor, coal contribution is 47.5% while less than 1% for nuclear, wind and solar. Likewise, (CO_2EQV) showed similar outcome in this respect. In addition, the higher the efficiency (%) the lower the operating cost (USc/kWh). Consequently, results showed that poor rating for solar (8.7c/kWh) & wind (5.1c/kWh) which is due to their low generation rate in comparison to cost effective nuclear (2.4c/kWh), hydro (2.2c/kWh) and NG (2.2c/kWh) power generation process. In conclusion, energy sources were grouped as nonrenewable (fossil fuel), renewable and nuclear. Whereby linking all risk factors, favors renewable and nuclear sources while nonrenewable gave environmental damaging effects in most rating aspect.

1. INTRODUCTION

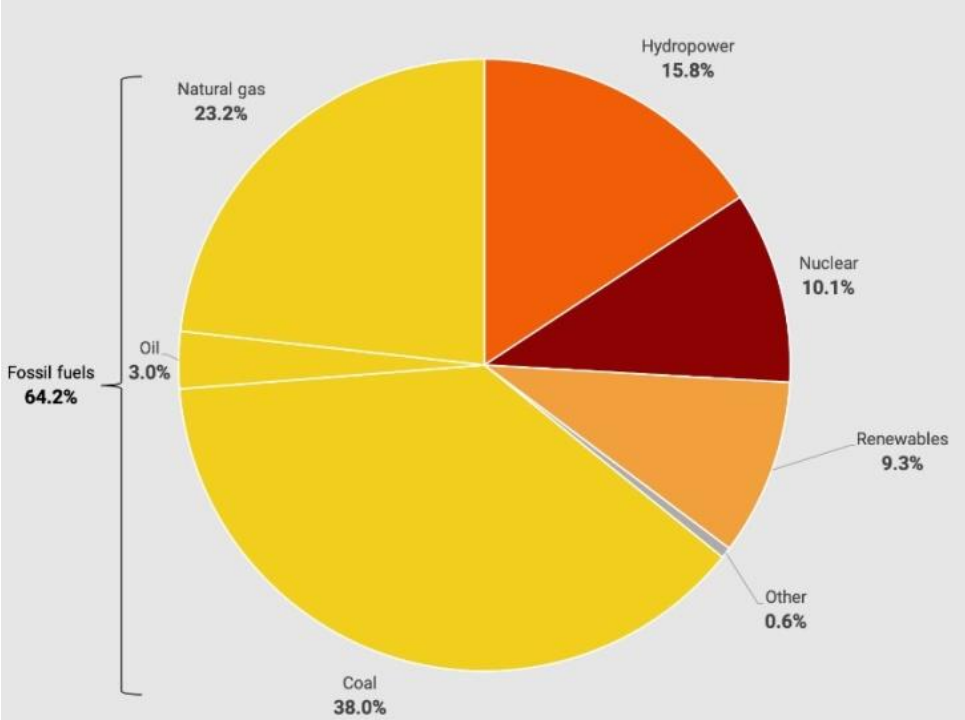
In earlier times, all human tasks were performed by man himself. However, the last three centuries have witnessed a spectacular advancement in science and technology. Consequently, production of "mechanical & electrical" equipment operated by different energy source have assisted human beings in their activities. Such energy sources may be classified as:

a. Renewable such as biomass, wind, solar, hydro & geothermal;
b. Nonrenewable fuel such as oil, natural gas and coal (fossil);
c. Inclusion of nuclear energy in the renewable and/or nonrenewable list is a research subject of major debate. Therefore, nuclear energy will be considered as a class by itself in this study.

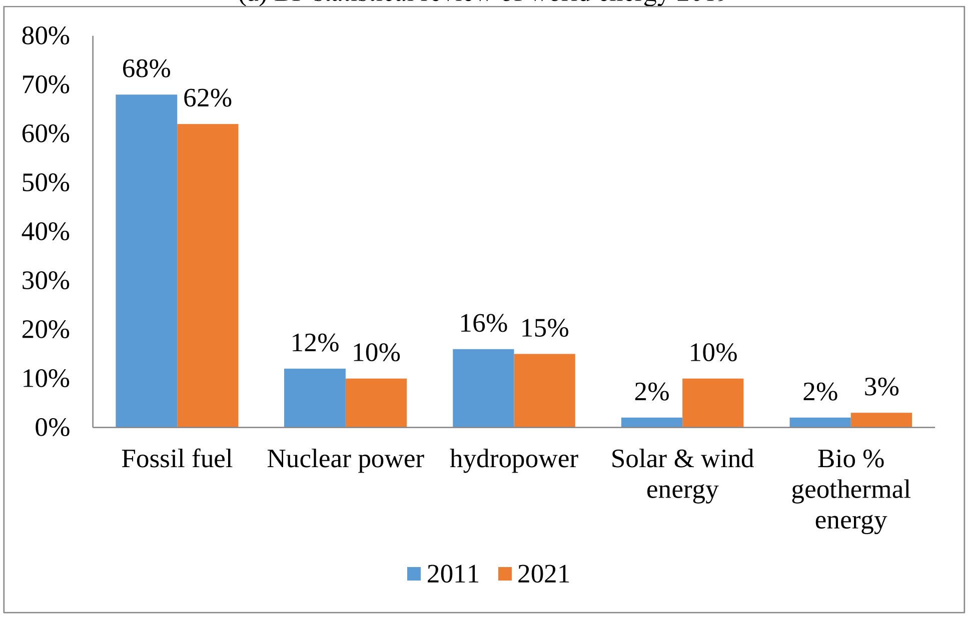
Whether renewable; nonrenewable or nuclear, each inherits certain characteristics that merit consideration whenever there is a need to examine or design a power plant for electricity generation process.

In addition, the Policy Maker, concerned with development of the national grid system, should focus on all resources that have established themselves commercially and cost effective for on-grid applications. While the Plant Management duty ought to maintain adequate power production for consumer's satisfaction, as most people take the safe operation of power generation for granted, which should be adequate, continuous and cheap. At the same time, Power Plant Engineers have to stay alert for any signs of impending equipment failure, and manage the unexpected & unaccounted for, or may be indirect causes that may leads to operational accidents of unpredictable magnitude of damages. Therefore, electricity in our everyday life is important. Enhancing obviously our productivity, comfort, safety, health, and economy.

This study will focus on the main energy sources, namely, renewable, nonrenewable and nuclear in relation to their environmental impact and effective cost, and in terms of the specified rating factors. Finally, the objective of this paper is to study, analyze and assess the "risk effect weight" of the different kind of energy sources used to operate power generation plants. Thereafter, to conclude a risk level for all groups of energy sources and their appropriate application.



(a) BP statistical review of world energy 2019



(b) Share of renewable energy in power, 2011 and 2021

Figure 1. The global energy consumption for electric power production

Nuclear generated electricity, although debatable in their safety and waste disposal, is unique in that it inherently addresses many of the short-comings of the other means for power generation. The use of nuclear power provides answers for many problems in the areas of the environment, economics, reliability, sustainability [1]. While, technologies for utilizing renewable energy can produce power, heat or mechanical energy by converting either to electricity or motive power. Such energy source does not release any kind of greenhouse gases. Thus, no harm will be done to nature in any way. Although attractive in terms of cleanliness and economic feasibility, nevertheless it has its own source of environmental problems. Unlike the high cost and limited sources of fossil fuels that release lots of pollutant gases to atmosphere, thus harm both the environment and the living beings [2].

Consequently, environmental considerations urge for electricity generation control. Since, pollution is one of the major risks from power plant. Introducing thereby, chemicals, particulates, or biological materials that cause discomfort, disease, or death to humans, harms other living organisms such as food crops, as well as causing great environmental damage [3-6]. Hence, such risk factor can be greatly reduced by implementing clean renewable energy source. This fortunate fact creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other needed requirements for present and future generations, making sure that life have and will continue to have, air, water, materials, and resources to protect human health and environment. Thereby, life existence will be sustained. Important as it is, renewable energy in fact is still considered in the development stage with respect to the magnitude of power demand world wild. As the global energy consumption from renewable sources are still in the range of 28% as demonstrated in the shown statistical chart Figure 1(a) [7, 8]. While Figure 1(b) [8-10] represents the share of energy production worldwide.

Unfortunately, 62% of world electricity generation is from burning fossil fuels [9], which produces carbon dioxide and other harmful emissions that add to the greenhouse gas already in the atmosphere, contributing thereby to global warming. Whereas 28% of electricity is generated from hydro schemes (rivers, dams, ocean waves and tides), wind, solar and geothermal power plants which are considered as clean energy sources and consequently produces practically no carbon dioxide or other harmful emissions and so are good for sustaining clean environment [9]. In addition to pollution aspects, all forms of energy sources used for power generation, may be subjected to accidental systems failure which can be as much dangerous to environment. This becomes quite obvious, since modern energy systems use materials that are combustible (gasoline), explosive (LNG), toxic (fumes), radioactive (enriched uranium fuel), and mechanical stress failure (hydroelectric dams), thus, causing environmental hostilities. Such systems, thereby, might be subject to explosions, fires, structural collapses and meltdowns, floods, contaminations, and other tragic events, resulting in loss of lives, shatter families & communities, and cause immense property damage.

The Environmental Protection Agency (EPA) [11], is the largest worldwide scientific establishment, which has deep concern about electricity and its environmental affects, reported that "All forms of electricity generation have some level of environmental impact, in that it produces more pollution than any other single industry. Fossil fuel power plants produce environmental problems on land & water, such as air emissions, thermal releases, solid waste disposal, ash disposal coal, and noise. On the other hand, nuclear power plants have one environmental issue no other form of electrical power plant does. An accident at a nuclear power plant may release large amounts of radioactive particles, resulting in a direct loss of life, and rendering a large land area immediately around the plant unlivable. In contrast, electricity from renewable resources generally does not contribute to local air pollution since no fuels are combusted in these processes, thus environmental problems are at a minimum. Specific interest is hydro plants which may help with flood control, flow regulation, or reservoir recreational projects. However, many things in hydropower plant can go wrong due to various reasons such as for example, dam collapse, penstock rapture, and turbine failure, as well as, risks to workers and public may also arise during dam construction [12, 13].

The above and similar published literatures have concentrated on a descriptive and statistical safety rating related to one kind of energy source. Nuclear power is probably the only exception to adapt a specific (INES) rating scale, which is a numerical power plant nuclear accident rating tool used to explain and classify the size of a radioactive materials release in such plant accidents and thus present the safety measure of such events and their impact on people & environment.

However, in respect to above argument, further rating factors were considered for overall energy source assessment, as defined below:

1) Death rate (DR)-This is the DR from accidents & air pollution measured as death per terawatt.hr of energy production, where (1 terawatt.hr) is the average annual energy consumption for 27000 people. The data given as (% DR) which represent the safety rating factor for every energy source [9].
2) Greenhouse emissions (CO_2EQV)-This is the emission of CO_2 equivalent per gigawatt.hr of electricity over the cycle of power plant, where 1 gigawatt.hr is the average annual electricity consumption of (160) people. The data given as % CO_2EQV which represent the cleanliness rating factor for every energy source [9].
3) Capacity factor (CF)-This is a comparative method linked to all energy sources as a measure of operating efficiency that indicates the ability of a generating plant to deliver its full capacity. Therefore, it basically measures how often a plant is running at maximum power, where a plant with a capacity factor of 100% means it's producing power all of the time. It is, thereby, an indirect indicator of the reliability of supply [14], and can be expressed for a given period of time simply as:

$$\mathrm{CF} = \left(\frac{\text{actual electrical energy}}{\text{max electrical energy}}\right)$$

4) Reliability (R_{bt})-Is the overall consistency that a system will perform its intended function adequately for a specified period of time, or will operate in a defined environment without failure and produces similar results under consistent conditions. In simple words, the system can provide power whenever it is needed. Unfortunately, reliability is affected by several factors such as (location of the plant, operation time of the day/year, storage of energy source, the weather conditions) [15, 16].
5) Generating Plant efficiency (η)-Generation efficiency of electric power plant (η) with respect to fuel used, is another rating factor [17, 18]. Which is defined for specific period of time as:

$$\eta = \left(\frac{\text{useful electricity output}}{\text{energy value of the energy source}}\right)$$

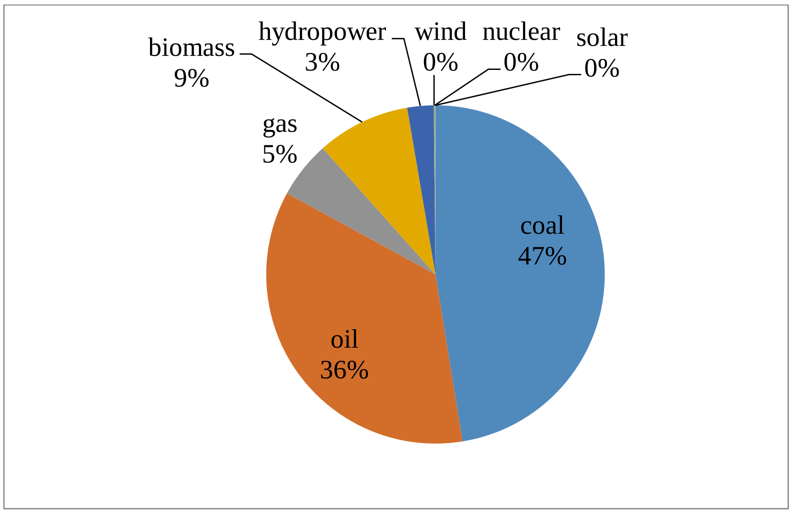
The difference between the input & the output are various internal & external losses that the unit may experience in the form of mass, heat and mechanical losses. Leading to very high cost-effective operation if the power supplied to consumers is kept at the demand level.

6) Cost factor (Cst_f)-In general, there are three principal components of electricity generation costs. These can be summarized as "capital; operating; & fuel" costs. Each of these three components are reflected by their reference cost to build, finance, maintain, and operate power plants and the electricity grid network [19, 20].
7) Global energy sources production (P_{rd}) is in the range of (27812 TWh) [9].
8) Global energy consumption (E_{cons}) when using energy more efficiently is one of the fastest, most cost-effective ways to save money, reduce greenhouse gas emissions, create jobs, and meet growing energy demand. However, the total world electricity consumption is in the order of (27812.74 TWh) [9].

These eight rating factors DR, CO_2EQV, CF, R_{bt}, η, Cst_f, P_{rd},

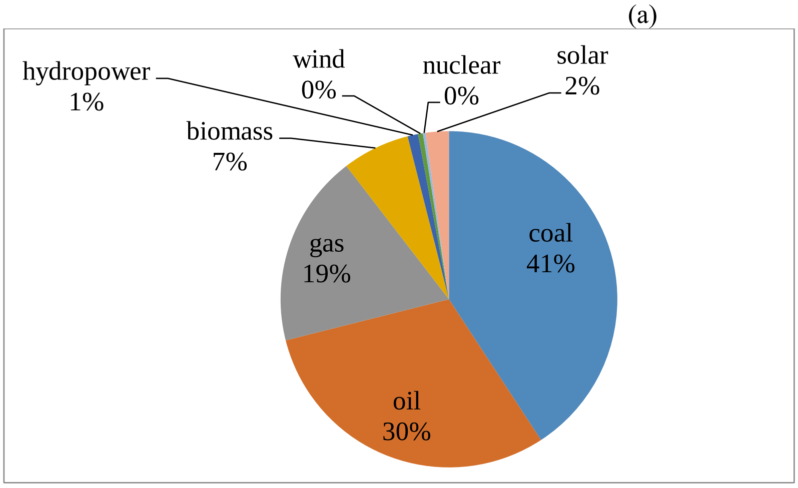
E_{cons}, will be considered in this analysis, and be abbreviated as such throughout this document.

"Our World in Data Org." have published an interesting statistical diagram titled "what are the safest & cleanest sources of energy?" as shown in Figure 2 [9, 10, 21], which represent two distinct rating scales applicable to all type of energy sources, and thus, each scale can be used to examine the performance of all types of energy source. These two rating scales are (DR & CO_2EQV) as mentioned above.



Energy source	Measures as death per TW-hr of electricity generation One TW-hr is the annual electricity consumption of 150,000 citizens in the European Union	
coal	24.62	47%
oil	18.43	36%
gas	2.82	5%
biomass	4.63	9%
hydropower	1.3	3%
wind	0.04	≈ 0%
nuclear	0.03	≈ 0%
solar	0.02	≈ 0%

(a)



Energy source	Greenhouse gas emissions "Tons" of Emission of "CO_2EQV" per GW-hr	"%" of Emission of "CO_2EQV" per GW-hr
coal	970	41%
oil	720	30%
gas	440	19%
biomass	78-230	7%
hydro	24	1%
wind	11	≈ 0%
nuclear	6	≈ 0%
solar	8-83	0.039%

(b)

Figure 2. (a) Safety & cleanness of energy sources in "DR"; (b) Safety & cleanness of energy sources in "CO_2EQV"

2. ACCIDENTS AND FAILURES

When the two terms "power" and "environment" are brought together, a friendship has to be established between them for the sake of mankind. Otherwise, disasters will eventually take place, causing death of many lives; monetary damage, regional affected, and may be an expensive late to-come lesson.

However, and in respect to energy sources, most of the energy utilization cycles involve some major accidental risks, which would occur due to structural or mechanical deficiencies; process failures; human errors or external natural phenomena. Assessment of the economic costs associated with severe accidents may allow a comparison between the different fuel cycles. However, to date very few studies have been dedicated to this point, except for the nuclear fuel cycle.

Pollution usually creates problems in a huge magnitude with may be long term but slow damaging effects, and man with his sophisticated knowledge and technology has been able to deal with these problems and thus managed so far to maintain a definite distance away from disasters. But accidents related to nuclear, hydro and wind power generation facilities are in fact of blink nature-comes sudden, destroy fast, and eventually ends quickly-but their many consequences may remain for a long time, destroying things gradually, and man can do nothing about it.

Disasters caused by power plants accidents necessitate further consideration to assess the effects of power generation plants on our environment. To reach, therefore, a clear and better understanding of such series matter, examples of accidents in all kinds of power generation plants are considered for this analysis. These examples present a brief study of the accident nature, causes and consequences.

2.1 Nuclear power plants accidents

The International Nuclear and Radiological Event Scale (INES) shown in Figure 3 [22, 23], is just like earthquakes or temperature ratings, which would be difficult to understand without the Richter or Celsius scales. Accordingly, events are classified on the scale at seven levels, where the severity of an event is about 10 times greater for each increase in scale level.

Benjamin K. Savacool has reported the literature's largest list of civilian and military nuclear incidents [19, 20]. However, as for power plant consideration, it has been identified that 33 serious incidents and accidents at nuclear power stations since the first recorded one in 1952 at Chalk River in Ontario, Canada. Of those, six happened in the US and five in Japan. The UK and Russia have had three a piece [22-25]. These results are shown in Figure 4.

Accidents that had extra worldwide attention are "Chernobyl Nuclear Power Plant Disaster – 1986 Ukraine, and "Fukushima Nuclear power plant – 2011 – Japan" both were rated as level 7 major accident for their huge destruction magnitude.

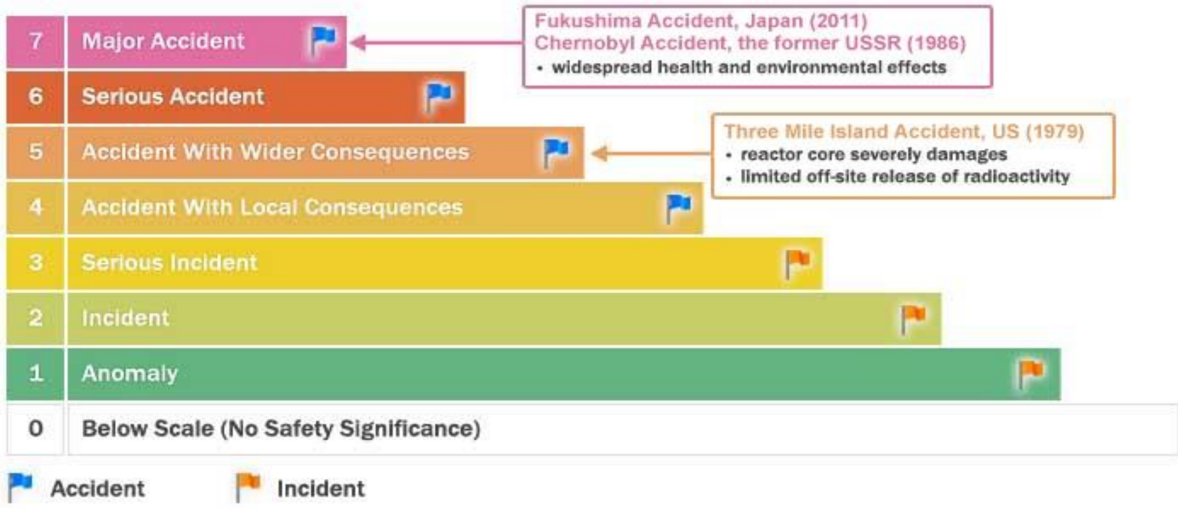


Figure 3. INES scale for various levels of accidents and incidents

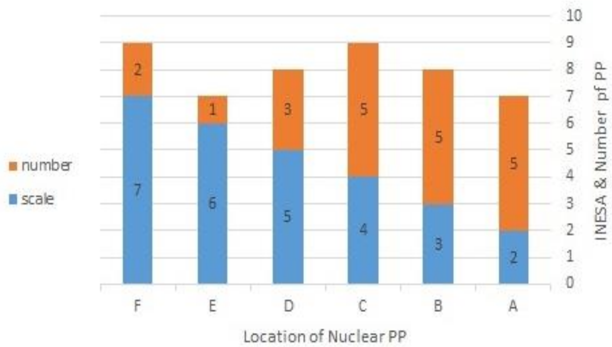


Figure 4. INES rating for various nuclear power plants

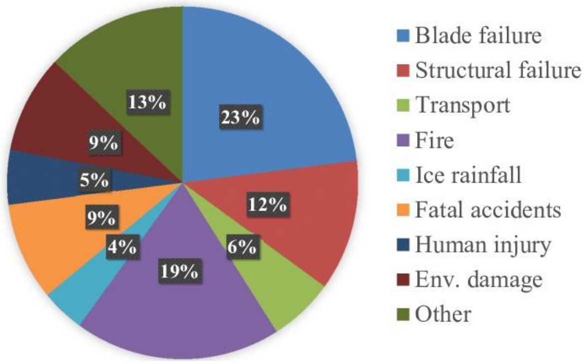
2.2 Thermal plant accidents

The most serious thermal plant accidents occur mostly within the plant area, although the neighboring districts may be affected somehow [26]. On other hand, most accidents were caused by fire incidents associated with steam generator compartment and transformers switching equipment. However, in addition to air pollution, it is the waste disposal of coal fired plants that actually represent the most damaging threats to local community and residential districts such that happened in Tennessee town of Kingston-USA, where the coal ash storage dam has collapsed, spilling thereby about 1.1 billion gallons of toxic coal ash crumbled, over approximately 300 acres. The estimated clean-up costs are expected to exceed $1.2 billion [27, 28].

2.3 Renewable power generation accidents

Hydro power plant is liable to different kind of system failure, which may lead to catastrophic accident, due to the enormous mass of water involved with its tremendous magnitude of kinetic & potential energies. The worst hydro power plant accidents are Banqiao Dam (China) & Sayano - Shushenskaya Dam (Russia). The first dam failed due the extra-ordinary amount of rainfall in addition to poor engineering and construction [12]. While the second dam failure caused by the head cover stud failure, where 41 studs had fatigue cracks destroyed by tension in addition to unit excessive vibration, load rejection or governor failure [13]. Solar systems, on the other hand have their share of accidents, too. Silane (a key chemical for solar cells) explosions [29] cause considerable death rate over the last 20 years. In addition, scientific experts have noted that solar manufacturers pollute streams and natural waterways in China. Likewise, wind power system accidents can cause considerable threats to living beings and raises serious concerns to the community living in a nearby residential area, especially with modern huge turbine blades size that can be over 100 meters length. Accidents associated with wind turbine are mostly due to turbine fires as demonstrated in Figure 5(a) components failure & malfunctions; structure failure; and ice throws. All of these threats are illustrated in Figure 5(b) [30, 31].

(a)



(b)

Figure 5. (a) Wind turbine fire incident; (b) Main components percentage failure

3. RESULTS AND DISCUSSION

Examination of various energy sources for power generation plants have been conducted specifically in respect to its environmental impact, safety, availability and cost. Whereby, efficient generation process reduces the amount of fuel required per unit power generated, and eventually reduces the corresponding emission and overall environmental effects, and thus presenting practical improvement measures for environmental protection.

Such findings are the key to locate the cross point for all energy sources assessment with respect to all rating factors DR, CO_2EQV, CF, R_{bt}, η, Cst_f, P_{rd}, E_{cons}. The discussion of such results as follows:

(1) Informative risk factors on people and environment were deducted from, "Our World in Data Org." 2021 updated statistical diagram shown in Figure 2 [9], capacity factor [15], generating plant efficiency [16, 17], reliability [15], cost factor [16, 17]. These rating factors are presented in Table 1. Also included in this table are the global energy production and consumption [8, 9].

As seen from this table, all energy sources differ in both effects and magnitude, where fossil fuels are the dirtiest & most dangerous by far, while both renewable and nuclear are vastly safe & clean. Analytically, the risk factor as a percentage contribution of each energy sources may be better form of rating as shown in Figures 6(a) and (b). Furthermore, this figure may offer better understanding if both effects are superimposed in one illustration as in Figure 6(c), from which the following are concluded:

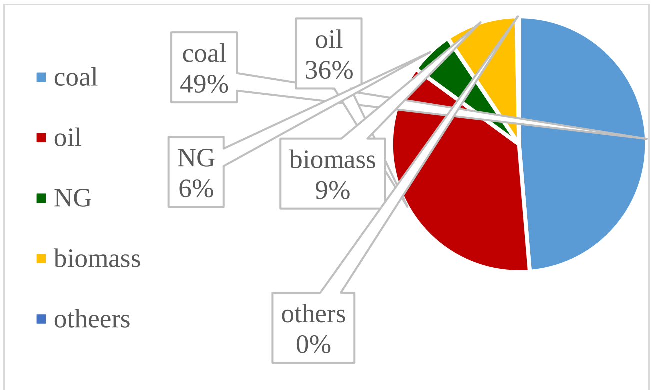
a) Energy sources from coal, oil, NG and biomass are the worst in most considered respects.
b) while, as surprisingly as it seems, nuclear sources cause 0.14% for both effects and could not even appear in the figure due to its very low effect value.

Similar to nuclear source conclusion, for wind, solar and even hydropower sources.

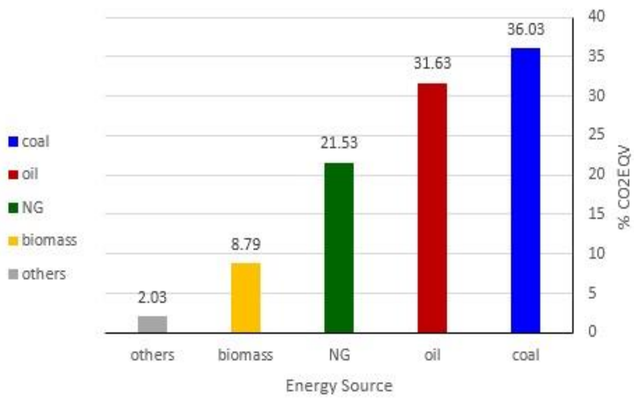
Therefore, the conclusive remark in this respect is that fossil fuel (Hydrocarbon) forms the major risk factor on planet earth climate. Such danger, in spite of its slow damaging effects, attack life for a very long period of time. Thus, slowly damaging air, water and land, and consequently to human life, animals and crops.

(2) Since "CAPACITY FACTOR (CF)" represent the fraction of system maximum power generation, then it is simply regarded as another good comparative method link to all energy sources. Accordingly, Energy Information Administration-USA (EIA), published (2021) values of CF for common energy sources in relation to power generation systems. These values are presented in Table 1 and illustrated in Figure 7(a) as CF for each energy source separately, and Figure 7(b) as fraction of each one to total max output of all energy sources. The latter may offer better representation for comparative purposes. These results are also in favor of nuclear and renewable sources, although coal shows good CF rating.

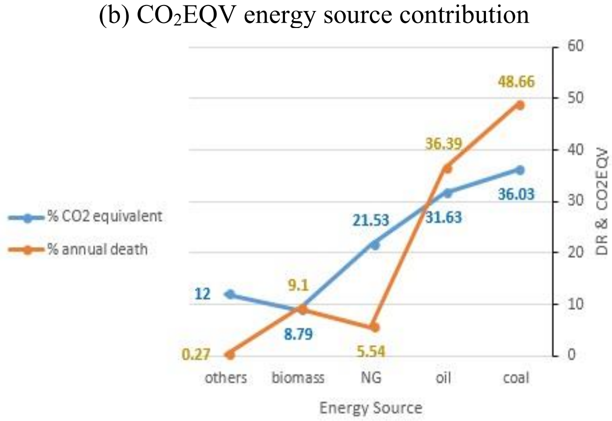
(3) The definition of reliability raises an important question, "which energy sources are the most reliable?". Taking reasons of (plant location, operation time of the day/year, storage of energy source, weather conditions) into consideration [14], renewable sources show comparatively low rating, while nuclear came best, and moderate rating for the remaining sources. These results are illustrated in Figure 8.



(a) % DR energy source contribution



(b) CO_2EQV energy source contribution

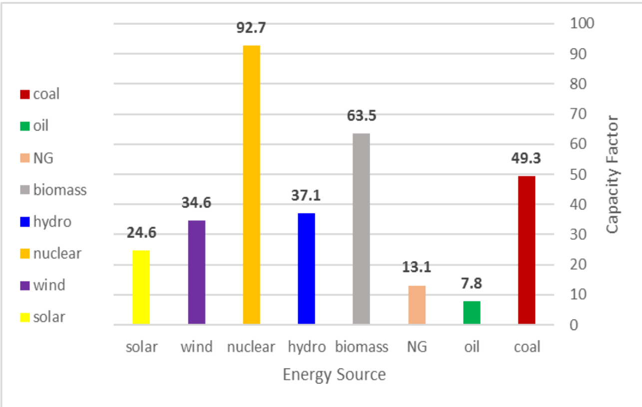


(c) DR & CO_2EQV effects

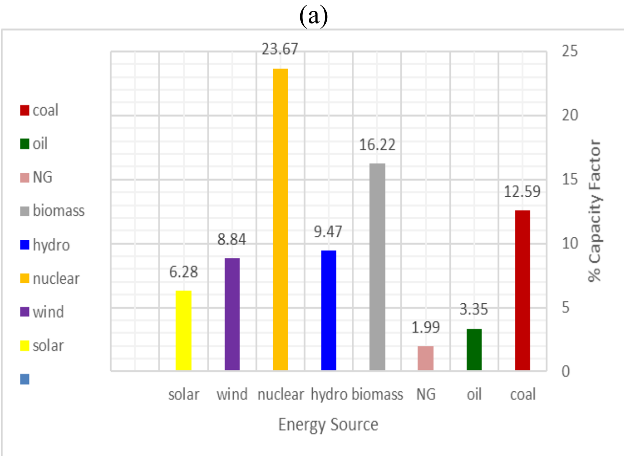
Figure 6. DR and CO_2EQV variation with energy source

Table 1. Deducted information from Figure 1(b) and Figure 2 [8, 9]

No.	Fuel	DR [10]	CO_2EQV [10]	CF [31]		Reliability [31]	Efficiency [17]	Cost [20]	% Global Production [8, 9]	% Global Consumption [8, 9]
		% annual	% annual	% CF	Σ% CF	%	%	US c/kWh	%	%
1	Coal	47.50	36.03	40.2	12.59	12.7	43	4.4	36.7	27.17
2	Oil	35.53	31.63	13.1	3.35	3.4	41	3.9	3.1	31.26
3	NG	5.41	21.53	56.6	1.99	14.1	39	2.2	23.5	24.66
4	Nuclear	0.05	0.14	92.7	23.67	24.1	35	2.4	10.4	4.29
5	Biomass	8.89	8.79	63.5	16.22	15.9	40		0.9	0.69
6	Hydro	2.51	1.49	41.5	9.47	9.4	92	2.2	15.8	6.83
7	Wind	0.07	0.18	35.4	8.84	8.8	35	5.1	5.3	2.97
8	Solar	0.03	0.22	24.9	6.28	6.5	17	8.7	2.7	1.65
9	Geo			74.3			75		0.3	
10	Others	0.01	0.01	24.6	18.13	5.2			1.6	0.46



(a)



(b)

Figure 7. Energy source capacity factor

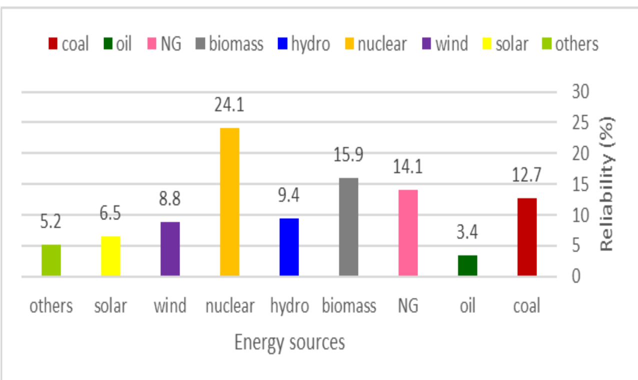


Figure 8. Energy source reliability

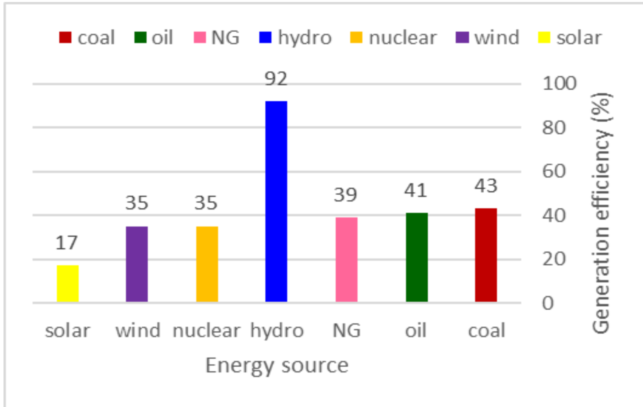


Figure 9. Generation plant efficiency [17]

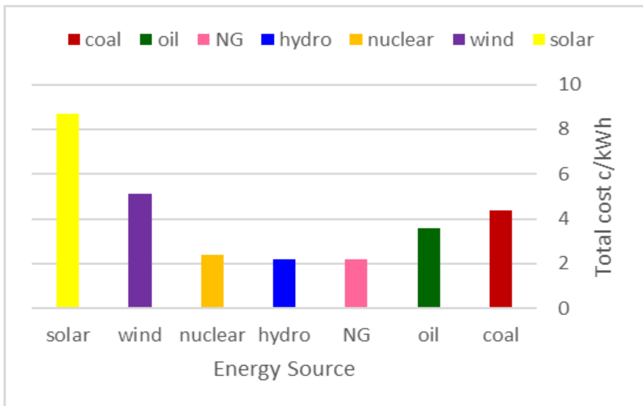


Figure 10. Electricity production cost for various energy sources

(4) Generation efficiency

Heat rate is one measure of electrical power plants efficiency that convert a fuel energy into heat and electricity. In other words, electric power plant efficiency (η) is the ratio between net electricity generation output from the unit, in a specific time and the energy value of the fuel supplied within the same time. Net generation, however, is the amount of electricity a power plant supplies to the power transmission line connected to the power plant, which accounts for all the electricity that the power plant consumes to operate the plant's generator(s) and other equipment, such as fuel feeding systems, boiler water pumps, cooling equipment, and pollution control devices. Furthermore, different energy source has different conversion limitations. Obviously, the higher the efficiency, the better in terms of cost. Figure 9 generation efficiency for different energy source plant [17, 32].

(5) As for cost assessment, many aspects must be considered when determining the cost of electricity generated by a given plant. As summarized previously, "capital; operating; & fuel" costs are the key factors. Each of which may reflect a reference cost to build, finance, maintain, and operate any particular system as well as the overall national electricity grid network. Accordingly, cost estimate that includes "capital, O&M, & fuel" presented in terms of (US c/kWh) [20] were added in Table 1 and illustrated in Figure 10 below. Surprisingly, solar & wind shows negative poor rating due to their low generation rate in respect to overall cost. Again, nuclear together with hydro and NG are well cost effective power generation sources.

(6) Clearly, it is important to link the effects of all risk factors to arrive at the final assessment of each energy source used to generate and satisfy worldwide electricity demand. Illustration of these results are presented in Figures 11(a)-(d) where as expected, all components of fossil fuels gave environmental damaging effects in most aspect of rating, while on the contrary, renewables proved to be a good clean & green resource. Nuclear power generation presented similar characteristics as renewable energy. However, public opinion still links such source with the two most damaging accidents in Chernobyl Nuclear Power Plant-1986 Ukraine, and Fukushima Nuclear power plant-2011 Japan, as both were rated as INES level 7 major accident for their huge destruction magnitude. In spite of that, these two major accidents were considered in evaluating nuclear power generation assessment, but did not affect its overall good rating among all power generation sources. These conclusions are better summarized in Figures 11(c) and (d), when energy sources were presented as groups of nonrenewable, renewable and nuclear, by which, the above rating of the three groups are yet reinforced.

(7) The results for renewable & nuclear rating although attractive, attention and concerns should be paid regarding their limitation and complexity.

- Considering renewable energy systems, has lots of advantages, including the fact it will never run out and does less harm to our planet. However, it faces several Limitations, such as:

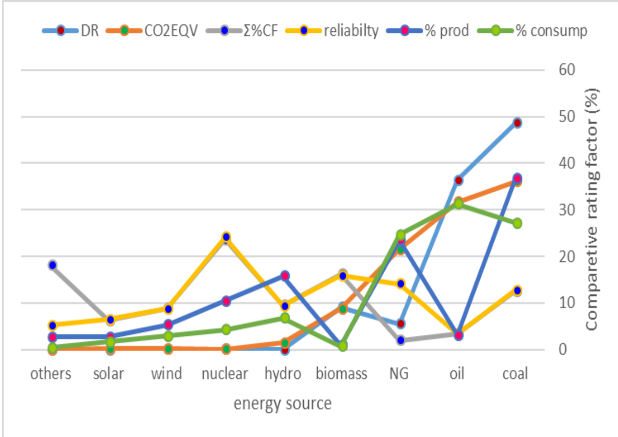
i. Reliance on weather conditions.

ii. Requires large space sites to establish productive energy project.

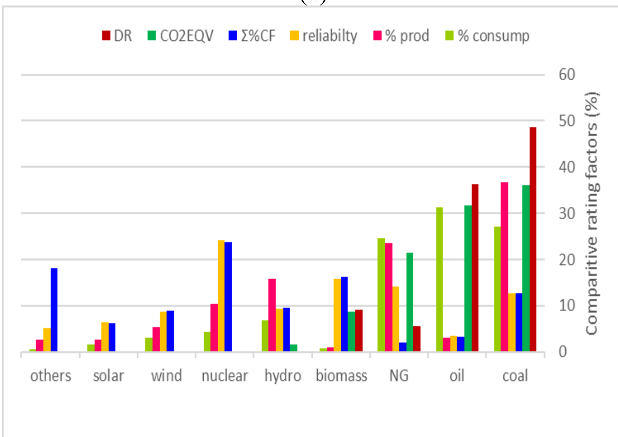
In addition to that, argument of complexities in renewable energy utilization requires synchronization in national grid electricity between the supply and distribution of renewable and non-renewable sources of power production and thereafter ensuring the stability and reliability of the national electricity networks.

- Nuclear on the other hand has its own limitation and complexity problems, where its limitations lie in taken the right decision to "Maintain public trust; Improve technical & economic performance; Minimization environmental impact during mining and operations; Elimination of radioactive waste; and Control and reduce nuclear insecurity"

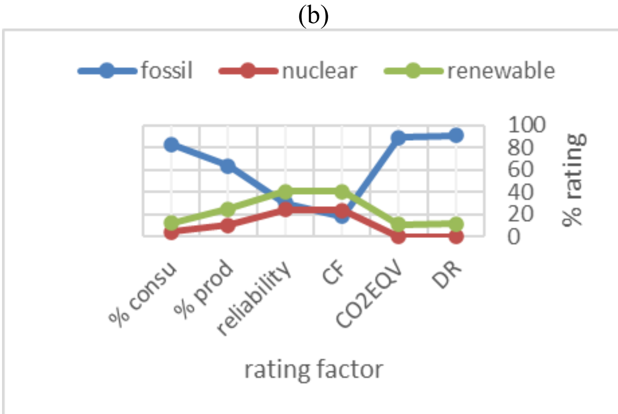
Nuclear power plants are the most complex and sensitive industrial installations, as they present high capital-intensive and long constructive time. In addition, Nuclear Power Plant control rooms heavily rely on complicated automation and computerized System Interfaces. Such interface presents the main information that has the greatest impact on the decision-making authorities.



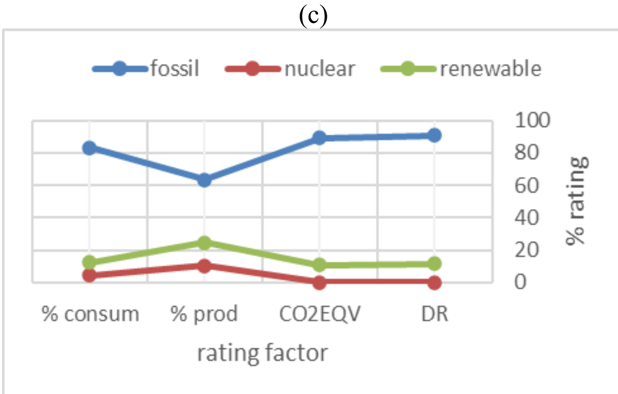
(a)



(b)



(c)



(d)

Figure 11. Risk factors effect from all respective energy source

(8) Furthermore, and in addition to above results, (Zero-One method) & (Mean for all energy sources method), are further rating strategies to be considered as assessment method. It should be noted that (0-1) method have been associated to Table 1 data, while Table 2 is Microsoft Excel evaluation results for Mean value of all energy sources. Details of these analysis are presented below.

i. Zero-One method

In mathematical logic a branch of algebra termed Boolean method is used, where results are denoted by "false & true" expression and are usually represented with 0 for false and 1 for true. Zero-One method is therefore used in this analysis as an overall energy sources weighing method where (zero is "-ve") and (one is "+ve") as presented in Table 3. This is to signal out clearly what to recommend as a safe and acceptable electricity generating sources in any plan of new projects. It should be noted that the "Zero-One" application results are shown in the last two columns of Table 1, which represents:

a) SAFETY is the effects on environment & people.
b) AVAILABILITY means how much each energy source is available to fulfill electricity power demand.

Accordingly, Table 3 constitutes the final rating of energy sources. Wherein, fossil fuel must consequently be rejected in terms of safety requirement. However, with the fast-growing energy demand and on account of its availability to cover the rising needs for electrical power to satisfy mankind energy requirement. Then, one has to just accept the safety factor consequences rather than face scarcity of power, especially at such places as health center life support equipment's, elevators and so forth. The decision makers should take into account the right location of the project in terms power needed and the corresponding project requirements available at that location, and last, one should search for the renewables where ever feasible.

ii. Mean for all energy sources method

In addition to (0-1) concept, the Mean for all Energy Sources approach is performed, which a statistical method generally applied for a given data set. Evaluation of such values is dividing the sum of all observations in a given data set by the total number of observations. using the formula:

$$mean = \frac{\sum sum\ of\ all\ observation}{number\ of\ observation}$$

Microsoft Excel mathematical evaluation is used, by regarding the rating factor values presented in Table 1 for all and every energy sources considered in this analysis. The results are then investigated and presented in Table 2 below. However, to establish a comparative evaluation, the variable value with respect to the mean values ought to be in a positive trend (1), otherwise its negative (0). Accordingly,

a. DR, CO_2EQV and COST should be lower than the Mean value, and therefore it is assumed positive and assign a value of (1). Otherwise, it is negative and thus assign (0) value.
b. CF, R and η should be higher than the Mean value and therefore it is assumed positive and assign a value of (1). If lower than mean value is obtained then (0) value is assumed.

Table 2. Results of mean energy source method

No.	Fuel	DR [10]	CO_2EQV [10]	CF [31]	Reliability [30]	Efficiency [17]	Cost [20]	% Global Production [8, 9]
		% annual	% annual	Σ% CF	%	%	%	%
1	coal	47.50	36.03	12.59	12.7	43	36.7	27.17
2	oil	35.53	31.63	3.35	3.4	41	3.1	31.26
3	NG	5.41	21.53	1.99	14.1	39	23.5	24.66
4	biomass	8.89	8.79	16.22	15.9	40	0.9	0.69
5	hydro	2.51	1.49	9.47	9.4	92	15.8	6.83
6	nuclear	0.05	0.14	23.67	24.1	35	10.4	4.29
7	wind	0.07	0.18	8.84	8.8	35	5.3	2.97
8	solar	0.03	0.22	6.28	6.5	17	2.7	1.65
9	geo					75	0.3	
10	others	0.01	0.01	18.13	5.2		1.6	0.46
Mean value		11.11	11.11	11.17	11.12	38.22	11.11	11.10

Table 3. Final energy sources rating by Zero-One method

No.	Fuel	DR [10]	CO_2EQV [10]	CF [30]	Reliability [30]	Efficiency [17]	Cost [29]	% Global Production [8, 9]	% Global Consumption [8, 9]	Safety (S)	Availability (A)
		% annual	% annual	Σ% CF	%	%	US c/kWh	%	%		
1	coal	0	0	1	1	1	1	1	1	0	1
2	oil	0	0	0	0	1	1	0	1	0	1
3	NG	1	0	0	1	1	1	1	1	0	1
4	nuclear	1	1	1	1	1	1	0	0	1	1
5	biomass	1	1	1	1	1	1	0	0	1	0
6	hydro	1	1	1	1	1	1	0	0	1	1
7	wind	1	1	0	0	1	1	0	0	1	0
8	solar	1	1	0	0	0	0	0	0	1	0
9	geo	1	1	1	1	1	1	1	0	1	1
10	others										

Table 4. Deducted information from Tables 1-3

No.	Fuel	DR % [10]	CO_2EQV % [10]	CF Σ% [30]	R % [30]	Eff % [17]	Cost US c/kWh [29]	% Global Production [8, 9]	% Global Consumption [8, 9]	Safety (S)	Availability (A)
1	coal	0	0	1	1	1	1	1	1	0	1
		0	0	1	1	1	0	1	0	0	1
2	oil	0	0	0	0	1	1	0	1	0	1
		0	0	0	0	1	1	1	1	0	1
3	NG	1	0	0	1	1	1	1	1	0	1
		1	1	1	1	1	1	0	1	0	1
4	nuclear	1	1	1	1	1	1	0	0	1	1
		1	1	1	1	1	1	0	1	1	1
5	biomass	1	1	1	1	1	1	0	0	1	0
		1	1	1	1	0	1	0	1	1	0
6	hydro	1	1	1	1	1	1	0	0	1	1
		1	1	1	1	1	0	0	1	1	1
7	wind	1	1	0	0	1	1	0	0	1	0
		1	1	0	0	0	0	0	0	1	0
8	solar	1	1	0	0	0	0	0	0	1	0
		1	1	0	0	0	0	0	0	1	0
9	geo	1	1	1	1	1	1	1	0	1	1
		1	1	1	1	1	1	1	0	1	1
10	others	1	1	1	0	0	0	0	0	1	0

Table 5. Deducted information from Table 1

No.	Fuel	DR [10]	CO_2EQV [10]	CF [30]	Reliability [30]	Efficiency [17]	Cost [20]	% Global Production [8, 9]	% Global Consumption [8, 9]
		% annual	% annual	Σ% CF	%	%	US c/kWh	%	%
1	Non-renewable	88.44	89.19	30.2	30.2	41	3.5	63.3	83.09
2	Nuclear	0.05	0.14	23.67	24.1	35	2.4	10.4	4.29
3	renewable	11.5	10.68	40.81	40.6	46	6.9	19.7	11.45

These results are nearly similar to those obtained from (0-1) method presented in Table 3. To fit and study the similarity among corresponding variables, both Tables 2 and 3 are combined in Table 4 in a respected trends to each fuel type and assessment factors. As anticipated, both methods gave comparable results, which may be concluded that, despite relying on different data source, close similarity is obtained.

Finally, the important aspects related to this project presented in Table 5 where fossil energy sources show negative results compared to renewables in terms of environmental effects. Cost rating however is well in its favor. More important, 83.09% of the world electricity needs comes from fossils while only 11.45% supplied from renewable sources. This is why statement of "one has to just accept the safety factor consequences" ought to be accepted. Yet, and at the same time, global series measure has to be taken in order to improve renewable energy sources power output to increase its share of world electricity demand.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The weight of each rating factor reflects the preference decision between all energy sources. Hence, appropriate selection of specific power generation system must satisfy the intended application. However, perfect selection is actually impossible, due to conflicted rating factors effects between these energy sources as shown in Figures 6-11.

Certainly, the most important factors are how to maintain clean & green environment, i.e. to keep (DR, CO_2EQV) as low as possible, and at the same time remain within acceptable economic level (Cst_f, η), where "capital; operating; fuel & waste disposal" are all cost-effective processes. Furthermore, "Safety & Availability" are extra concluded weighing factors, where safety is considered as key factor as long as energy source is available. Such results were summarized in Table 5.

Accordingly, fossil fuel came worst in most considered respects. while, nuclear and renewables are safe and clean sources. As a result, fossil fuel must consequently be rejected. However, with the fast-growing energy demand and on account of its availability to cover the rising needs for electrical power to satisfy mankind energy requirement is a good reason for reconsideration. Where, fossil energy sources represent:

a) 83% of the world power generation requirement
b) 63.3% of global energy source production

Therefore, one has to accept the safety factor consequences rather than face scarcity of power, especially at such places as health center; life support equipment's; elevators and so forth.

On the other hand, before the selection of power source for a specific application, the decision makers should take into account

I "location requirement" and "rating factor" limits as a guide for proper decision.

II power generation benefits must be balanced with its operation consequences.

III "consumers preference" and "end-user act" are just as important.

Accordingly, all types of power generation systems are considered depending on the above merits. Whereby, data presented in Table 6 for plotting Figure 12 are predicted from Table 4 by counting the number of ones & zeros for every energy source.

The final conclusions are:

1) Continue to use fossil fuel irrespective of its overall negative ratings, just for the reason of its availability to fulfill the global power needs, at the same time it should be gradually replaced by alternative safe sources of energy;
2) Join efforts of all mankind technology to improve renewable energy production rate, and thereby increasing its share of global energy demands;
3) Improve the safety requirement of nuclear power generation plant to join renewable source in replacing fossil fuel;
4) Gradual and balanced program to replace fossil fuel and at the same time maintain adequate energy production to fulfill worldwide requirements and avoiding any level of energy shortage.

Table 6. Final energy source rating

No.	Fuel	One	Zero
1	coal	7	3
2	oil	4	6
3	NG	7	3
4	nuclear	8	2
5	biomass	7	3
6	hydro	8	2
7	wind	4	6
8	solar	3	7
9	geo	9	1
10	others	4	6

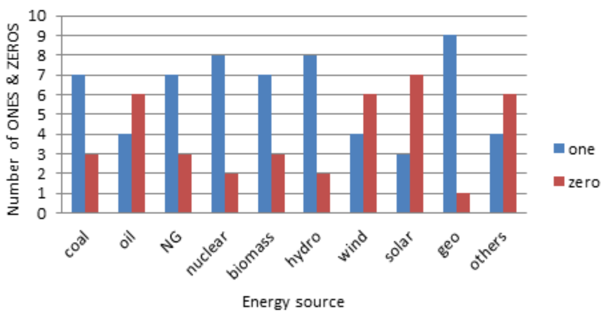


Figure 12. Final energy source rating

4.2 Recommendations

Recommendations for future consideration are of prime importance for the sake of mankind safety. Besides, with the serious international concern, the world needs a clear and comprehensive energy strategy that addresses the whole of the energy life cycle. Suggestion for future work:

i. Study the balanced choices between continued investments in fossil fuels versus more extensive development of renewable energy sources;
ii. Study management of waste disposal in terms discarding, destroying, processing, recycling, reusing, or controlling processes within the application of electrical power generation systems;
iii. Consideration of the variables that leads to consumers' preferences for particular types of power generation.

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