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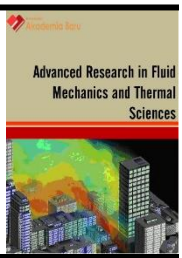


# Novel Approach of Quantifying Energy Security in terms of Economic, Environmental and Supply Risk Factors

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Muhammad Mutasim Billah Tufail[1,*], Jafni Azhan Ibrahim[2], Mustakim Melan[2], Mohd Nasrun Mohd Nawi[2]

[1] Iqra University (IU), Karachi, Pakistan
[2] School of Technology Logistics and Management Universiti Utara Malaysia, 06010 Kedah, Malaysia

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**ABSTRACT**

The rising global demand of energy and political instability has raised the issue of energy security more than ever before. Depleting reservoirs and environmental degradation encourage policy makers to review intended action plans for sustainable energy generation. Fluctuating oil prices and unforeseen political events has emerged a need of secure energy supplies policies. This study will incorporate three key integrated energy dimensions in terms of cost to evaluate the total exposure. Affordability, acceptability and availability of adequate supply are the factors to evaluate for sustainable economic growth, potential environmental harm and social stability. Energy experts and policy makers around the globe are looking for the effective tool to measure the impact of supply disruption on energy generation process. High level of security incurred extra cost; however, opportunity loss due to energy supply disruption has never been evaluated in terms of monitory unit. This study will focus on the evaluation of potential loss due to unavailability of supplies for power generation system. Holistic approach will be applied to measure the combine impact of fuels specifically used in power generation process. Besides the traditional approach of unit power generation cost this paper encompasses other cost parameters which indirectly affects the cost of generation in the form of carbon-tax penalty and the excessive cost of secure and reliable supply of energy resources to power generation system.

***Keywords:***
Energy Security, Levelized cost of energy (LCOE), Carbon Tax, Energy Supply Risk



## 1. Introduction

In modern society, the importance of electricity is paramount. Electricity is essential and is largely linked to several facets of life, because power is the lifeblood of human activities in the modern world. According to Gilbert [1], the tremendous advancement in modernization of technology is a contributor to the raised demand of energy in 21$^{st}$century besides rapid increase in the world population. IEA [2] reveals the facts that about 13 trillion watts of energy are being used worldwide. It has been foreseen by the experts that further requirement of 30 trillion watts would be needed by

*Corresponding author.
*E-mail address: muhammadmutasim@gmail.com (Muhammad Mutasim Billah Tufail)*

2050 due to rapid rise in global population and a brisk economic growth [3]. Currently world-wide approximately 87% of electricity is generated through fossil fuels. In 20th centuries fossil fuels were given preferences for power generation due to their comparatively cheaper prices [4]. Regrettably, it is a well-known fact that human health is severely affected by the catastrophic climatic changes caused by fossil fuels and their reservoirs are gradually depleting [5].

The importance of fossil fuel cannot be denied in modern world but their environmental consequences and depleting reservoirs emerge a need for affordable, sustainable and reliable alternatives for power generation. In this regard policy makers continuously update their policies and intended action plans to provide a secure, reliable and affordable supply of electricity along with lower level of risk. Fossil fuels reservoirs are not evenly distributed round the globe and highly depended upon the offshore trade. It has been observed that the unforeseen political events, extreme weather conditions and natural disasters affect the supply disruption in past which ultimately results in imbalance oil prices and economic growth instability. Although secure energy supplies are always remains the key consideration of policy makers but 100% security is never intended to achieve. Infect high level of security results in excessive cost [6].

This paper focused on the formulation of the equation to calculate the total cost of power generation mix. Five fuel policies of Malaysian power generation mix will be used to quantify the total cost exposure including coal, gas, hydro power, biomass and solar. The total cost will be divided into three segments of levelized cost of energy, penalty of environmental degradation in terms of carbon tax and the excessive cost of secure and reliable supplies.

## 2. Energy Security

Industrialization, economic growth and rapid increase in population imagers need of energy security more than ever before. It is critical to evaluate the secure supplies [7]. Generally, security is often portrayed as less reliance on imported energy, especially oil [8]. Energy security ranks as a top issue in many countries around the world [9,10].The terminology of energy security is not very new. Several authors have defined the term energy security but its concept is still unclear [11]. According to Sovacool [12] energy security is to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users". The most cited definition of IEA stressed on the uninterrupted physical availability of supplies at affordable prices, while keeping environmental concerns in mind [2]. The extensive work on energy supply security has been conducted by winzer [13]. He reviewed 36 definitions of energy security all of them are focused on the supply disruption risk, on other hand the economic prospective security of supply can be defined as availability of demanded energy volumes at a reasonable price [14]. Yergin [15] defined the energy security from the cultural and political aspects, the purpose of energy security is to maintain sufficient, reliable and affordable supplies of energy without sacrificing major national policies and agendas.

In past years many studies have been conducted considering and evaluating different dimensions of energy security. While the concept of energy security and supply risk will never be discussed commutatively. Particularly focusing on the concept portrayed by IEA [2] and Winzer [13] this study will formulate a new concept of energy security in terms of affordability, Acceptability and risk of supply insecurity as an indicators of availability as shown in Figure 1.

The three key interrelated dimensions of energy security are need to be analyzed for the efficient policy formation i.e. (1) Affordability for the evaluation of per unit power generation cost, (2) Acceptability to measure the impact of environmental degradation and (3) Availability for the assurance of uninterrupted supplies to electricity generation systems as shown in Figure 1. The objective function of the study can be written in terms of total cost exposure as

*Total Exposure (Minimum) = Affordability (Economic Loss) + Acceptability (Environmental penalty) + Availability (Cost of opportunity loss caused due to supply unavailability)* (1)

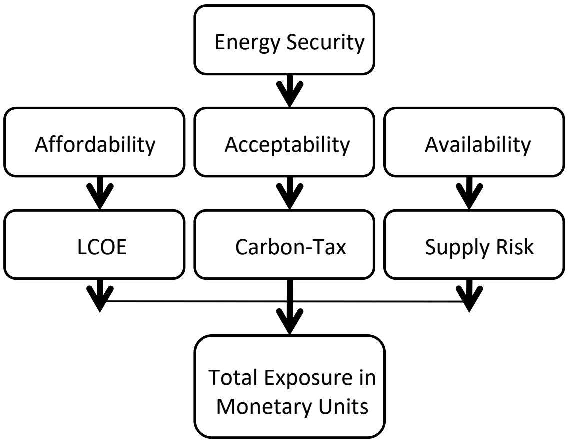


**Fig. 1.** Energy Security Framework

## 3. Economic Analysis (Affordability)

Affordability is always been a key consideration of policy makers, although it is directly influenced by the other external factors considerably demand and resource availability. A reduction in supply allows prices to rise and demand to fall, while an upward shift in demand raises prices and, hence, supply. In 20$^{th}$ centuries fossil fuels were given preferences for power generation due to their comparatively cheaper prices. After 1970 oil crisis, the use of fossil fuel became unreliable and heavy fluctuation in oil prices has been observed. Referring to latest collapse oil prices fell from a peak of 115 US $ per barrel (US$/bbl) in June 2014 to less than 50 US$/bbl in January 2015[2]. This was a break with several years of prices lowering in a narrow band around US 100 $/bbl. It was also against widely held expectations. According to the resent forecast by International Energy Agency the steady prices will increase for many years to come and will be expected to reach once again to 112- 116 US$/bbl by 2020 [2,16].

While oil prices shocks are always dramatic when they occur, large and unexpected swing in oil prices are not new, from 1970 to 2016 the fluctuation in oil prices has been observed between 5 to 115 US$/bbl [17]. The impact of lower fossil fuel prices hurt producers but eventually beneficial for consumers. In simple words it can be said that oil prices volatility badly hurts the economy, one consequence of these combined effect is that reduction in oil prices do not benefit economy as much as price increase hurts it.

Conclusively, dependence on fossil fuels energy has a volatile penalty. Measures to reduce this dependence can help prevent economy harm. Option includes reducing the energy intensity of the economy, improving energy efficiency and last but not least maximizing the share of non-fossil energy (Renewable). The potential of the Renewable energy market can be assessed by conducting techno-economical evaluation of different electricity generating technologies. Technology cannot be considered as favorable until unless it is not cost effective. As stated by Larsson [18], the economic evaluation of renewable technologies-based power generation is extremely influenced under cost of generating electricity. Electricity generation cost can be calculated with several methods, among which LCOE is widely used.

According to IEA and NEA [19], LCOE considered as a suitable method to measure per unit generation cost of different technologies over their economic lifetime. It can also be used as an efficient tool for the ranking of power generation technologies on the basis of cost effectiveness [19,20]. It is in actual the net present value of total lifetime cost of energy system, which involves capital investment cost, fixed and variable cost, plant and equipment cost, fuel cost etc., divided by the total amount of electricity generated in the lifetime of the system [21].

It is frequent using technique to evaluate power generating cost of different generation technologies [22]. The extraordinary feature of this technique may use to make comparison between conventional power plants and renewable sources, example (solar power, wind hydropower) etc., although all these technologies have dissimilar cost formation. Conventional technologies have fixed to variable cost function while in comparison renewable energy contain high fixed cost and slightly variable cost. It provides input to economic models used in technology of power generation systems, and energy related issues to update policy [23].

IEA (International Energy Agency) and NEA (Nuclear Energy Agency), DECC (Department of Energy and Climate Change), CASES (Cost Assessments for Sustainable Energy Systems), NEEDS (New Energy Externalities Development for Sustainability) and EUSUSTEL (European Sustainable Electricity) all of these organizations used definitions of levelized costs of energy generation (Table 1) identical the formula as presented in Eq. (2) [18].

$$LCOE = \frac{\sum_{t=1}^{N} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{e_t}{(1+r)^t}} \tag{2}$$

where

$I_t$ Capital Investment
$M_t$ Operation and maintenance cost
$F_t$ Fuel cost
$(1+r)t$ Discount rate
$e_t$ Total energy produced by the system
$N$ Life of the plant

**Table 1**
Levelized cost of energy generation. Source: EIA Annual energy Outlook (2015) [24]

| Plant Type | Cap. Factor (%) | LCC | Fix. O&M Cost | Var. O&M Cost | Trans. Invest. | Total System LCOE |
|---|---|---|---|---|---|---|
| Conv. Coal | 85 | 60.4 | 4.2 | 29.4 | 1.2 | 95.1 |
| Advanced Coal | 85 | 76.9 | 6.9 | 30.7 | 1.2 | 115.7 |
| Conv. Gas combine Cycle | 87 | 14.4 | 1.7 | 57.8 | 1.2 | 75.2 |
| Advanced Gas combine cycle | 87 | 15.9 | 2 | 53.7 | 1.2 | 72.6 |
| Biomass | 83 | 47.1 | 14.5 | 37.6 | 1.2 | 100.5 |
| Hydroelectric | 54 | 70.7 | 3.9 | 0 | 2 | 83.5 |
| Solar PV | 25 | 109.8 | 11.4 | 0 | 4.1 | 125.3 |
| Solar Thermal | 20 | 191.6 | 42.1 | 7 | 6 | 239.7 |

It is understood that the renewable energy resources are costly in comparison with conventional energy resources but the low environmental harm makes it more favorable for policy makers to implement. However, Intermittency risk is the factor need to be evaluated.

## 4. Environmental Impact (Acceptability)

It has been proven that expected increase of GHG (Greenhouse Gas) emission in atmosphere would result in variation of seasonal scale in temperature in many countries around the globe [25-27]. The increase of GHG will create numerous hazards for human civilization in coming years. The fourth report of climate change was published by the IPCC anticipated that the global temperature was expected to increase from 2-4 and even 8 $^0$C in coming 100 years. Although it appears to be the minor change but it is most rapid change in last 10,000 years [28].US Environmental Protection Agency (EPA) has also admitted that atmospheric concentration of GHG has tremendously increased in the last fifty years from 312 ppm 1950 to 401 ppm 2015 [29] which is responsible to raise global temperature, sea level, patterns of rainfall, intensity of storms and reduces plants growth and productivity, marine life and chemistry of the oceans [30].

The consumption of fossil fuel as an energy resource in a population is one of the huge challenges to global environmental sustainability and economic stability. Greenhouse gases “GHG” and chemicals that evolved during the combustion of fossil fuels are the biggest threat to human health. However, Fossil fuel burning is responsible for contributing 67% of the entire emission globally [31]. Among the GHG $CO_2$ is the most abundant gas produced by human activities [32] released as a by-product in the combustion process of fossil fuels, namely coal, natural gas, and petroleum products [33]. Following the natural phenomena partial amount of $CO_2$ has been absorbed by the oceans, but as emission increased, the consequential edification of those oceans leads to the climate change and global warming [34]. Today, the worldwide population is using about 17 trillion watts of power which is accountable to release 32,190 mmt of $CO_2$ in the atmosphere [16]. Coal burning was responsible for 43% of the total emissions [35]. Electricity generation (and heating) currently contribute approximately 25% of global anthropogenic greenhouse gas emissions, the primary driver of observed climate change [36]. Indeed, as much as a third of oil, half of gas and over four-fifths of coal reserves must be left unburned for global warming to stay below 2 degrees Celsius [37]. Some of energy sources along with their ability to release carbon are shown in Table 2.

**Table 2**
Different fuel types and amount of carbon release. Source: Sovacool, (2008) [38]

| Fuel | Capacity/Configuration/Fuel | (gCO2e/KWh) |
|---|---|---|
| Coal | Various generator types | 960-1050 |
| Natural gas | Various combined cycle turbines | 443 |
| Biomass | Short rotation forestry reciprocating engine | 41 |
| Solar PV | Polycrystalline silicone | 32 |
| Solar thermal | 80MW, parabolic trough | 13 |
| Hydroelectric | 300 kW, run-of-river | 13 |

It has been acknowledged that the unsustainable use of fossil fuel release hazardous gases in environment which is injurious for living things and poses a major threat for human health [39]. The concern of international communities and scientific organization has increased in restricting upheavals of GHG atmospheric concentration rather than disputes and disagreements of scientific facts [28,40], therefore they are more focused of inducting environmental friendly strategies in formulation of new policies. It is a fact that after the reveal of stern [40] report many countries have beginning/initiated to reduce the use of hydrocarbons and highly encourage the carbon reduction alternatives in manufacturing industry and production process and engage cleaner fuel renewable energy like wind, solar, biomass and water current. In continuation to this several global communities have promised to reduce carbon emission.

In the recent published 5$^{th}$ assessment report of IPCC (2014) it once again stressed to adopt the carbon restriction strategy over several decades to achieve the temperature maintaining target by the end of 21$^{st}$ century [41]. To cater the rising trend of GHG some countries has implemented an efficient economic measure "carbon-tax" in their nation policies [42]. However, the policy makers, scientist and economist have agreed that the taxation technique will effectively reduce carbon footprint. Some developed nations like Denmark, Finland, Netherlands and Sweden have been collecting carbon-tax more than a decade. Country like China also proposed carbon-tax in its national action plan and would expect to implement by 2020 [43]. In electricity generation industry carbon price for the generation of 1KWh of electricity can be calculated bas [44]:

$$C_i = C_a C_b \sum n_x \tag{3}$$

where

$C_i$ is the cost of carbon released during generation of electricity.
$C_x$ is the amount of carbon released by x type of technology in KWh.
$C_p$ is the price of per metric ton of carbon released.
$n$ is the number of unit generated.
$x$ Type of fuel (Coal, gas, Hydropower, Biomass, Solar).

## 5. Supplies of Resources (Availability)

Fossil fuel reservoirs are gradually depleting. It is estimated that coal will last 164 more years, oil 200 years, natural gas 65 years, and not fossil, but non-renewable, nuclear resources will be available for the coming 70 years [45]. A more prudent estimate shows a grimmer picture of coal, oil and gas lasting for 107, 35 and 37 years, respectively [46]. The importance of oil can never be ignored in modern life but its depleting reservoirs, environmental concerns and energy security emerges the needs of alternative sources which reduced the dependency from oil in efficient way.

As it has already mentioned earlier that almost 87% of primary energy depends upon fossil fuels and its adequate availability is very sensitive to modern society. A medium-term disruption in energy supplies can drag the whole world into economic crisis. Most of the crude oil reserves in the world are situated in regions that have been prone to political upheaval, or in region that have had oil production disruption because of political events. Several major oil prices shocks have observed at the same time as supply disruptions triggered by the political events, conspicuously the Arab oil embargo in 1973, the Iranian revolution, The Iraq-Iran war in the 1990's, and the Persian Gulf war 1990. More recently, disruptions to supply from political events have occurred in Nigeria, Iran, Iraq, Venezuela and Libya.

Considering the history of oil supply disruption caused by political events, policy makers constantly assess the possibility of future disruptions. In addition, the size, duration, availability of stocks and the ability of other producers for the diversification of supplies are also under consideration. Despite political interference weather also plays a significant role in the supply of fossil fuels and renewable energy. In 2005, hurricanes in Gulf of Mexico region shutdown oil productions and many petroleum refineries which ultimately results in high oil prices. Disruption in supplies always creates a high impact on prices. Considering the case of Malaysia cancellation, delay or default in coal imports may eventually raise the production cost as local market with high price remains the only option [47].

Similarly, renewable energy sources are also under influence of weather conditions and are not always available, cloudy days reduce he electricity generated from solar installation; without wind reduce electricity from wind farms; and droughts reduce the water availability for hydropower. Each and every resource is exposed to specific type of supply risk; therefore, there is a need to optimize all the resources for least cost at minimum exposed risk through diversification. Diversification in primary energy mix and global power generation resources is the key consideration of policy makers around the world.

## 6. Supply Disruption Risk (SDR) in Energy System

Defining energy security is also complicated by the variety of views of what is at stake: to some it means protecting against politically-induced supply disruptions or technically-induced supply problems, to others it is facing the challenge of terrorism or dealing with price shocks, while to many it means addressing the issue of global warming [48]. There is no consensus among economists, energy experts and politicians on the correct hierarchy of energy challenges for the world in the near to long-term future. Drawing across the core Energy literature and discussion with professional and academic colleague's five indicators of energy supply disruption has been identified as shown in Table 3.

**Table 3**
Key factors influence energy supply security

| Types of Risks | Reasons | Coal | Gas | Bio mass | Hydro | Solar |
|---|---|---|---|---|---|---|
| Geological Risk | Resource depletion/Shortage | ✓ | ✓ | ✕ | ✕ | ✕ |
| Geopolitical Risk | Political instability (war, Terrorism) high import dependence | ✓ | ✓ | ✕ | ✕ | ✕ |
| Economical Risk | Lack of investment on extraction of resources | ✓ | ✓ | ✓ | ✓ | ✓ |
| Technical Risk | Plant equipment malfunctioning / Failure | ✓ | ✓ | ✓ | ✓ | ✓ |
| Climatic Risk | Extreme Weather conditions | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Intermittency Risk | ✕ | ✕ | ✕ | ✓ | ✓ |

Less or more each and every type of fuel is associated with supply disruption risk, which may result in electricity generation shortage accountable to produce opportunity loss. Reliance on single resource will lead to many complications in future. Therefore, the major concern of policy makers round the globe is to seek for the optimum and secure power generation solution which minimizes the occurrence of supply shortage for generation systems. In this regards this study introduces a new approach to quantify the risk of disruption of each supply and its impact on generation industry. The total risk exposure of each and every source will sum up together to analyze the commutative possible occurrence of disruption and its impact in terms of monitory unit. On the bases of above identified indicators the total supply disruption risk of any type of fuel is consist of five major factors and can be evaluated by the general form of equation i.e.

*Total supply disruption Risk in power generation (SDR) = (Geological Risk + Geopolitical Risk + Economical Risk + Technical Risk + Climatic Risk)* (4)

## 7. Result and Conclusion

To evaluate the minimum cost exposure considering the three integrated dimensions of energy security final equation can be formulated as

*Total Exposure (Minimum)= LCOE+Ci+SDR* (5)

$$TE\ (Min)\ =\frac{\sum_{t=1}^{N}\frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{N}\frac{e_t}{(1+r)^t}}+\ C_aC_b\sum n_x+\sum SDR$$

The objective of this study illustrates the development of a new tool to measure the energy security, which is based on compliance with the principle of sustainability, pragmatism and applicability. Particularly the majority of processes appear to measures have supply oriented without including the environmental or social aspects, although the definition of it encompasses the energy security not only supply rather. Inter alia, government should provide uninterrupted and affordable energy to its citizens required for the social wellbeing without harming the environment. The study also aims to propose a new concept of energy security by introducing the measurement of supply disruption risk and its impact in terms of monitory unit to evaluate the total cost exposure. It also highlights the impact of carbon emission on total generation cost. Regardless of the fact that energy security is one of the key contemporary issues, but the accurate measuring of energy security is impossible. This study believes in the optimization of available resources for the sustainability in power generation process. LCOE, carbon tax and excessive cost of secure supplies has been added up to give the total cost exposure of power generation mix. The novel approach can be further modified and include other cost related parameters to make the tool more realistic and practical.

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