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Conceptualizing Energy Security and the Role of Diversification as the Key Indicator Against Energy Supply Disruption

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ABSTRACT

The importance of energy in modern civilization can never be denied. Developing and emerging economies of 21st century are facing dual challenge of Affordable and socially acceptable supplies of energy to its consumers. The security of energy supply and resources is one of the key objectives of global energy policies. However the concept of energy security, indicators and attributes are still unclear. The major focus of the wealthy countries of the world is to make the energy more clean and sustainable at any cost. However for developing and struggling nations the major object is to get the cheap and consisting supplies of energy for better development. This paper elaborates the terminology of energy security with respect to Availability, Accessibility, Affordability and acceptably and discuss the role of diversification in mitigation of security risk. It also highlights the indices of diversity measurement in energy system.

Keywords:
Energy security, energy diversity, Shannon Wiener index (SWI), Herfindahl-Hirschman index (HHI)

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1. Introduction

Unpredictable energy market and rising supply related threats are making energy security an significant issue globally [1-2]. The basic challenge that underlies the global economic growth and human development is a fundamental requirement of reliable, affordable, clean and secure energy supplies. The terminology of energy security is not very new. It always play vital role alongside with energy supply and demand, but it never got the attention indeed. The rapid technology advancement has no doubt has been assisting people in many ways [3]. In the beginning energy was only available to industrial sector and some of wealthy households. The requirement of energy was increased when it become available to a number of growing societies. Today, it becomes think less life without electricity, hot water in every house, not having any transport for daily mobility. Demand of energy is growing every corner of the world with increase in population and changing

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lifestyles. But what is energy security? Is it just a balance between demand and supply of energy? Or it is something more? Number of researcher tried to find this answer in past.

2. Energy Security

Energy security and energy services are mutually inclusive with each another. Secure energy services are essential for national security, economic growth and political stability. Traditionally energy security is only associated with the secure and reliable supplies of oil [4-5]. The concept of energy security amends after the 1970 oil crisis and includes the dimension of accessibility related to the price manipulation of exporting countries [6-7]. Later in late 90's energy security terminology address other issues beyond oil supplies [8]. Now a day's energy security is considered as the integral part of national policies and also considered as the top issue in many countries around the world [9-14], but the concept of energy security is still unclear. As energy security has different meanings to different people at different moments in time, an exact definition of energy security is difficult to present [15]. International Energy Associate (IEA) defines energy security as uninterrupted availability of energy commodities at price which is affordable, while keeping the environmental concerns in mind [16]. According to Bielecki (2002) [17] energy security is to provide adequate and reliable supplies of energy consistently meeting the demand of global economy at affordable price. However, Sovacool [18] defined energy security as to even handedly provide affordable, efficient, reliable, affordable, environmentally clean, proactively governed and acceptable (in terms of social needs) to the consumers. Bohi and Toman [19] defined energy insecurity as the loss of welfare resulting from a change in the price or physical availability of energy.

2.1 Convensional 4A Framework of Energy Security

The classic definitions of energy security, more focus on the availability and affordability of energy [20-21]. The four "A"s framework of energy security presented by the Asia Pacific energy Research council (APERC) was actually the modified form of world energy council's three sustainability objectives (The 3As). The three sustainability objectives consist of Accessibility, Availability and Acceptability however APERC added 4th A as Affordability [22]. The report was not able to justify its contents from previous research neither from empirical analysis or logical reasoning [23]. Later the terminology of 4 A's are further elaborate and extended to the meaningful form in terms of "Availability" to assure the uninterrupted physical availability of supplies. Accessibility" the available resources are also accessible, "Affordability" must be cheap and affordable and "Acceptably" should not harm environment [4,22,24-26]. Chester [27] also addresses toward the 4A's framework, his study includes (Availability, Affordability, Adequacy and sustainability).

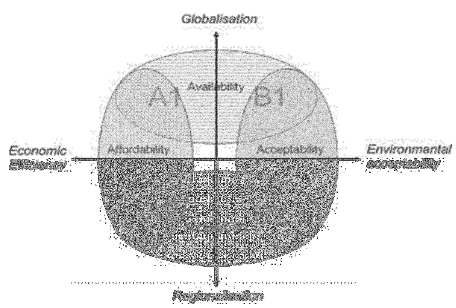

Fig. 1. Indicators of energy Security [4]

Cherp and Jewell [23] criticize Conventional 4A's framework in several different ways. The first legacy of four A's framework is, it's not proper define for whom energy should be acceptable and affordable. Affordability can be defined in different prospective like consumer point of view from the investment point of view, it may be profitable [22], from consumer side, it may be the low price of energy [4-27] while government may consider it as intensity of subsidy or Export/Import stability [28]. While acceptability and environmental concern have given equal weightage by APERC [22].The conventional four A's fails to portrayed a complete picture of environment concern, its acceptability varies with the state of actors, acceptability level is different among the local population industries, states and environmental NGO's. It is unclear about the social norms, type of energy system and linkage between them. The classic definition of energy security focuses on the self evidence and implicit linkage between national values an (independent oil and territorial integrity) and actual energy system (supplies of oil). The concept of energy security extends beyond the domain of oil to other energy sectors, and replaces the conventional geographical values with economic welfare, also domestic political and domestic stability.

Risk identification is the basic stage of firm's risk [29-30] however the Conventional 4A's Framework also does not include the concept of "risk and reliance". Winzer [31] addresses toward the risk of availability in his research. He describes "natural source of risk" with "availability" and "human source of risk" with accessibility", while economic activities are associated with "affordability" and finally "acceptability" highlights the environmental cancers.

2.2 Modern Perception of Energy Security

The modern concept of energy security deals with the low vulnerability critical energy system [32]. The system is not considered to be secured until unless it is capable enough to act against the risk. On the other hand a secure supply chain system plays an essential role to provide quality energy related services. The supply chain system may be complex and include many steps, for example (extraction, transportation, conversion, transmission, distribution and final consumption). The system may extend beyond national borders [33].

According to Luft and Korin [34], definition of energy security depends upon the need of the countries and the situation of vulnerability of energy supply in the region. They further argued that the distinction between the two primary energy consumption sectors (transport and electricity) in important to explain the particular energy situation. Most vulnerable countries are those whose needs are heavily dependent upon energy imports in both sectors. The only dependence on resource import in power generation provides at least a chance for diversification. Electricity generation fuel mix consist of coal, oil natural gas, renewable and nuclear power, among these resources coal is dominant in generation sector while oil in the transportation.

2.3 Dimensions of Energy Security

The concern of energy security began mostly on securing access to oil and other fossil fuels. However, the old energy security rationales which were only focused particularly on oil and physical availability are becoming less salient due to diverse energy markets and the transformation and use of energy [10]. In addition to the transformation of energy security definition, many new dimensions of energy security have begun to surface. Several factors such as rising energy costs, volatility of energy price, uncertainties about available imports of energy, and concern about climate change and air pollution [35-36] have altered the dimensions of energy security. Therefore, a workable framework of energy security dimensions needs to be more comprehensive in order to analyze a holistic perspective of energy security. This is important to yield greater understanding about energy security in a broader sense for both energy exporters and importers [10].

Several institutes and researchers are working to develop new dimensions of energy security. For example, Asia Pacific Energy Research Centre has defined four dimensions of energy security – availability of resources, accessibility of resources, environmental acceptability, and affordability [22]. Von Hippel *et al.,* [37] have further expanded the work by APERC to several other dimensions. They included energy supply, economic, technological, environmental, social cultural and military security in energy security dimensions. Another work based on APERC dimensions can be traced to Sovacool and Brown [38]. They defined energy security in term of availability, affordability, energy and economic efficiency, and environmental. This work then has been further modified by Sovacool and Mukherjee [25] their modification of energy security dimensions included availability, affordability, technological development and efficiency, environmental and social sustainability, and regulation and governance as shown in table 1.

Table 1
Dimensions of energy security

Dimension	Components
Availability of Energy Supply	• Sufficient supplies of energy • Reliable energy system and energy mix of the system • Using domestically available energy sources • Dependency of imported energy supply • Diversification of energy sources and suppliers • Prudent reserve to production ratios
Affordability of Energy Services	• Affordable and stable energy services prices • Accessible and equitability to all population
Technology Development and Efficiency	• Promoting innovation and research into energy system • Resilience and adaptive capacity • Sufficient investment and employment • Promoting energy efficient among consumers
Environmental and Social Sustainability	• Mitigation efforts for controlling pollutions and climate change • Balance of energy spending budget for consumers
Governance of Regulations, Policies, and International Cooperation	• Clear energy regulations and policies • A stable and transparent regulations and policies • Participant from authorities in making regulations and policies • Promoting educating public • Commitment toward international cooperation

2.4 Indicators of Energy Security

Energy security indicators are use to measure the dimensions of energy security. The main prospective of indicators is to stabilize the energy security from unforeseen events, provide in depth risk exposure to policy makers [39] and secure system from supplier monopoly of increasing prices. Sovacool and Mukherjee [25] divide indicators of energy security into two components (1) simple indicators and (2) complex indicators. Simple indicators are used to quantify physical and financial values where as complex indicators deals with the measurement of diversity in the system. Energy diversity is an important element that needs to be considered while formulating the energy policy for a country. Energy system is considered to be more secured if is highly diversified.

2.5 Importance of Diversification in Energy System

Diversity of fuel supply and resources for energy has received increasing attention globally in recent years as a result of rising energy prices and increasing recognition of risks of supply disruptions and price volatility in world fuel markets. However the industrial utilization of fossil fuel is also responsible for carbon emission which directly harms environment and effects on human lives [40]. The concept of diversification is revolves around the famous proverb "*Do not put all the eggs in one basket*". According to Yergin [8], the strength of energy security depends upon the policy of diversification used in the system. Diversity is the state or quality of being varied or different [41]. Diversification is applicable to an energy system and considered as the key to system's energy security. Hughes has illustrated the different views of diversification: one such view is the use of similar form of energy to meet the demands of the energy service with different supplier, signalling the replacement of a less secure source of energy with the one that is more secure. Such as, after 1970 oil crisis The U.S. government decreased oil trade from Asian counties by substituting from Canada, Nigeria, Mexico and Venezuela [42]. In some conditions, introducing, or changing new infrastructure that permits alternative energy sources, thereby replacing existing ones is regarded as a form of diversification and generally applied to electrical generation; One such example occurred in late 1970s, when increasing costs of oil contributed to the first oil shock of the 1970s, the world-wide change of energy source takes place from oil to coal and nuclear for electrical generation [42].

In Stirling's studies of diversity and characteristics of diverse energy systems, diversity is described in different contexts, including social, cultural, economic, scientific and technological factors [43]. The dependence on a variety of symbiotically disparate suppliers and their energy supplies is known as energy diversity, and is seen as an essential component for energy security. The uncertainties and risk associated with an energy system can be reduced by diversity, while enhancing its energy security [44]. According to Stirling, three general, necessary but individually insufficient properties of energy diversity are: **Variety:** "The different numbers of available alternatives that can be used in diversification" and it can also be defined as available options or portfolio of energy resources. **Balance:** "It is a proportion of distributed energies among the system". It relates to the evenness or relative abundance of the different energy sources. **Disparity:** " The manner and degree in which energy options may be distinguished" [43].

2.6 Diversity Valuation Indices

Diversification in energy supplies, resources and transportation is a significant, and sometimes the only option of risk mitigation and protection against large losses in case of event risks. Energy diversity metrics often cited in energy literature generally are derived from two fields: ecology and business. The two most common methods of diversity indices are Herfindahl-Hirschman Index and Shannon-Wiener Index [4,37,45].

2.6.1 Shannon-Wiener Index (SWI)

Diversity valuation method in energy system was launched by Stirling in 1994 [46], with the application of Shannon Wiener index in energy portfolio. The major assumption behind the development of the index is to emphasis on security related threats while making energy policies. Shannon-Wiener Index (SWI) which was primarily intended to be used in analyzing the vulnerability and the other characteristics of the biological systems. In this index Shannon used the idea of "entropy" and gives higher weightage to rare species in comparison to abundance perception. The

Shannon-Weiner Species Diversity Index is calculated by taking the number of each species, the proportion each species is of the total number of individuals, and sums the proportion times the natural log of the proportion for each species. Since this is a negative number, we then take the negative of the negative of this sum. The higher the number, the higher is the species diversity similarly transforming in energy system the higher the number of the fuels, the higher the level of energy diversity. SWI can be calculated by

$$H = -\sum_{i=1}^{S} P_i \, lnP_i \quad (1)$$

Formula for Shannon Wiener Index, where,
H: Shannon's diversity index
S : Total number of fuel in the Generation (richness)
Pi: Pi is the proportion of generation represented by the ith type of generation
Lnpi: Equitability (evenness)

The greater the value of H, the higher the system diversified. The index assumed more reliable means to calculate diversity in energy because it includes the conception of balance and variety [46]. In ecosystem the index repeatedly applies for the stability. Shennon Weaver equation was used by templet [47] to analyze the number of different economic behaviour exist in a system and how evenly energy is allocated among them. The minimum value considered by the index is zero, when there will be only one source of generation. According to Grubb *et al.*, [2], when the Shannon–Wiener Index is below 1 it indicates a significant lack of diversity, whilst an index higher than 2 indicates a diverse fuel mix which means that there is no overreliance on certain options. However, Hickey *et al.*, [48] acknowledge that one difficulty of using the Shannon–Wiener Index in energy diversity appraisal is that there is no "explicit range of values that would indicate excessive or insufficient fuel diversity". The better understanding can be acquired through Figure 2 which shows how the diversity index for systems of *n* equal independent contributions changes as *n* grow. A system having two evenly distributed sources contains value of diversification 0.69, and it increase with the number of increase in sources with 10 equal sources it would be 2.3 as shown in the figure.

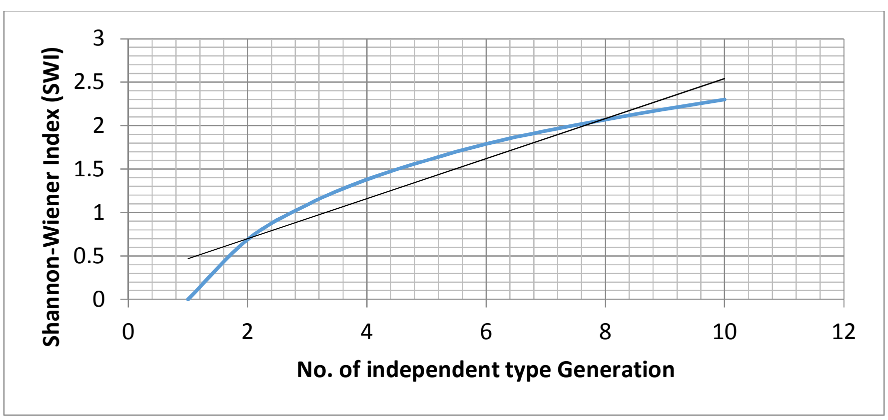

Fig. 2. Shannon-Wiener Index

2.6.2 Herfindahl-Hirschmann Index (HHI)

The quantification of diversification, a diversity score, in a portfolio may not be straightforward. The diversity score is defined as a measure of the degree of diversification for a given portfolio. One commonly used method of measuring the degree of diversification is the Herfindahl-Hirschman. HHI is a detailed study to estimate the portfolio concentration using aggregate data.

It has been widely applied in the electric power industry to evaluate the impact of mergers and acquisitions on regional electricity market concentration. In the context of fuel diversity measurement, the HHI is calculated as the sum of the squares of the market share of each resource category, as shown in the following formula

$$HHI = \sum_{i=1}^{N} C_i^2 \quad (2)$$

Where *Ci* is the market share for the *i*th resource, expressed as a percentage of the total, and *N* is the number of resource categories in total.

Let consider a power generation portfolio *P* consisting on 5 different generation technologies C_i where i=1 to 5.The value of diversification across five different generation technologies can be measured using HHI, where

$$HHI = C_1^2 + C_2^2 + C_3^2 + C_4^2 + C_5^2 = \sum_{i=1}^{5} C_i^2 \quad (3)$$

If there is only one supplier the index is 1, if there are five suppliers of the same size the index is 0.2. If there is one dominant supplier with 90% of the market, and only one other supplier with 10%, then the index is 0.82. A lower index means greater diversification of supply. The reciprocal (1/H) of the Herfindahl index can be viewed as the number of equivalent suppliers. Figure 3 shows that a system having two evenly distributed sources contains value of diversification 0.5 and it decrease with the increase in number of sources, at 10 equal sources the value would be 0.1

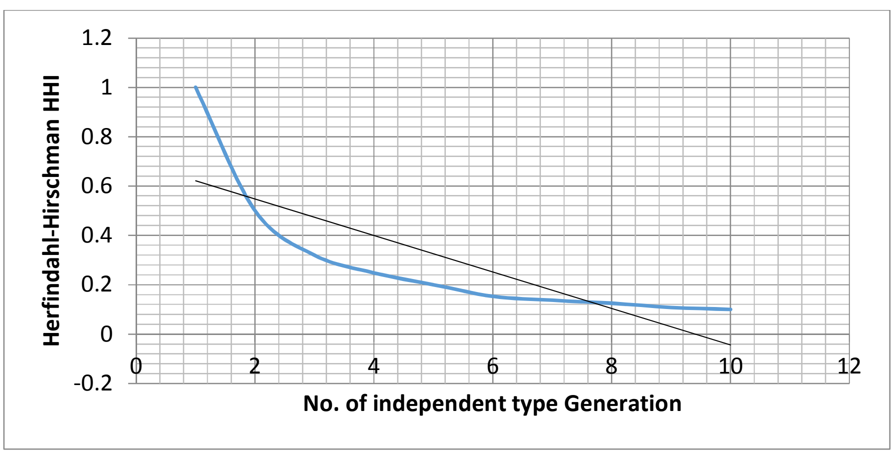

Fig. 3. Herfindahl-Hirschman HHI

4. Conclusion

After 1970 oil crisis security of energy supplies become one of the vital challenges for developed and developing economies. This study encompasses the notation of energy security from different authors prospective. It highlights the classic and modern concept of energy security. However the concept of energy security varies with respect to demographic conditions but commutatively emphasis on uninterrupted, secured and clean supply of energy at affordable price. The concept of Energy security has further divided into dimensions and indicators for appropriate measures. To enhance the level of security this study also discussed the concept of diversification either supply or resource prospective and conversed the two widely used indices HHI and SWI to measure the level of diversity in energy mix.

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