Uluslararası İktisadi ve İdari Bilimler Dergisi

IJEAS

A CRITIQUE OF ENERGY SECURITY MEASUREMENT[1]

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ABSTRACT: Although ensuring energy security is a key concern of the countries all over the world; measuring energy security remains a challenge. There are several indicators and indices to measure energy security. However energy security measurement is a complicated issue because of the difficulty and sometimes impossibility to measure its components. Because the components differ by regions, countries and also by periods. Besides each of the indicators and indices has its advantages and disadvantages. Despite the growing energy security research there is still not an accepted, single measurement method. This study presents a comprehensive analysis of energy security measurement referring to the indicators and indices used by international organizations and governments to make comparisons and to yield policies. It is aimed to call attention to existing vagueness as a barrier to get high-quality and reliable data.

Key Words: *Energy Security, Energy Security Measurement, Energy Security Indicators, Energy Security Indices.*
Type of Article :Research
Jel Classification : Q40, Q41, Q43
DOI : uiibd.832430
Received: *27.11.2020***/ Accepted:***18.12.2020* **/ Published:** *22.12.2020*

ENERJİ GÜVENLİĞİ ÖLÇÜMÜNÜN KRİTİĞİ

ÖZ: Enerji güvenliğinin sağlanması bütün dünya ülkelerinin ilgi alanında olsa da; enerji güvenliği ölçümü bir güçlük olarak karşımıza çıkmaktadır. Enerji güvenliğini ölçmek için çeşitli göstergeler ve indeksler bulunmaktadır. Ancak enerji güvenliği ölçümü, bileşenlerini ölçmenin zorluğu ve kimi zaman da imkansızlığı nedeniyle komplike bir meseledir. Çünkü bileşenler bölgeler, ülkeler ve ayrıca dönemler ile farklılık göstermektedir. Bunun yanısıra her bir göstergenin ve indeksin kendi avantajları ve dezavantajları bulunmaktadır. Giderek artan enerji güvenliği araştırmalarına rağmen halen kabul edilmiş tek bir ölçüm metodu bulunmamaktadır. Bu çalışma uluslararası organizasyonlar ve hükümetler tarafından karşılaştırmalar yapmak ve politikalar üretmek için kullanılan gösterge ve indeksleri dikkate alarak, enerji güvenliği ölçümünün kapsamlı bir analizini sunmaktadır. Kaliteli ve güvenilir data elde etmede bir bariyer teşkil eden mevcut belirsizliğe dikkat çekmek amaçlanmıştır.

Anahtar Kelimeler: Enerji Güvenliği, Enerji Güvenliği Ölçümü, Enerji Güvenliği Göstergeleri, Enerji Güvenliği İndeksleri
Makale Türü :Araştırma
Jel Sınıflandırması: Q40, Q41, Q43
DOI : uiibd.832430
Geliş tarihi: *27.11.2020***/ Kabul Tarihi:** *18.12.2020***/ Yayın Tarihi:** *22.12.2020*

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Kaynak gösterimi için:
KOÇASLAN, G. (2020). A Crıtıque of Energy Security Measurement. Uluslararası İktisadi ve İdari Bilimler Dergisi, 6(2), 37-51. DOI:

[1] The preliminary draft of this research was presented at the International Congress of Energy, Economy and Security that was held on 8-9-10 November 2019.

1. INTRODUCTION

Energy security is stated as a complicated concept which itself and its components need to be clearly identified and defined. Energy security is defined as uninterruptible supply of energy to meet demand at affordable prices (Dyer & Trombetta 2013; Martišauskas et al. 2018; Trombetta 2013; Badea 2010).

There are several research approaches to energy security from different perspectives (Kisel et al. 2016; Kanellakis 2013; Augustis 2012; Winzer 2012; Hughes 2012; Sovacool 2011; Ciuta 2010; Chester 2010; Christie 2009; Simpson 2007; Rogner et al. 2006). Uninterrupted and reliable and supply, affordable or reasonable price, energy diversity and availability are the most common concepts in the traditional definition of energy security (Martišauskas et al. 2018; Zhang et al. 2017; Sovacool 2016; Ren & Sovacool 2014; Sovacool 2013; Sovacool et al. 2012; Bambawale & Sovacool 2011; Sovacool et al. 2011; Jun et al. 2009; IEA 2008; Asif & Muneer 2007; Dorian et al. , 2006; Yergin 1988).

Improved by the Asia Pacific Energy Research Centre to assess energy security; accessibility, availability, affordability and acceptability are four multidimensional concepts known as 4As of the field referring to geologic or technical, to social and political, to environmental or social and to financial-economic issues respectively (Haar & Haar 2019; Linas 2018; Cherp & Jewell 2014; Winzer 2012; Hughes 2012; Jewell 2011; Valentine 2011; Badea 2010; Kruyt et al. 2009; APERC 2007).

It is critical to define energy security clearly. However even the definition of energy security is widely disputed in the literature (Azzuni & Breyer 2018; Martišauskas et al. 2018; Sovacool 2016; Laldjebaev et al. 2016; Cox 2016; Kisel et al. 2016; Krishnan 2016; Blumer et al. 2015; Faas et al. 2011; Chester 2010; Le Coq & Paltseva 2009; Kruyt 2009; Grubb et al. 2006). There is a considerable research that introduces energy security in terms of modelling of energy system resilience (Cox 2018; Martišauskas et al. 2018; Guivarch & Monjon 2017; Glynn et al. 2017; Oshiro et al. 2016; Guivarch et al. 2015; Lima et al. 2015; Gracceva & Zeniewski 2014; Jewell et al. 2014; Cherp & Jewell 2013; Jewell et al. 2013; Chaudry et al. 2009).

Energy security is an evolving, interdisciplinary and complicated concept which cannot be considered without the effects of global markets, vast cross-border infrastructure networks, primary energy suppliers, financial markets, environmental and social concerns and technological issues and countries have different priorities, economic growth rates, geopolitical position, climate conditions, wealth of energy resources and demographic indicators (Martišauskas et al. 2018; Radovanović 2017; Glynn et al. 2017; Ang et al. 2015; Brown et al. 2014; Chang 2014; Cherp & Jewell 2014; Månsson et al. 2014; Sovacool 2013; Winzer 2012; Sovacool & Mukherjee 2011; Leung 2011; Cherp & Jewell 2011a; Cherp & Jewell 2011b; Löschel et al. 2010a; Löschel et al. 2010b; Chester 2010; Vivoda 2010).

This study reveals a critique of energy security measurement. The rest of the paper is organized as follows. After a detailed definition and controversial issues are summarized in introduction part; energy security measurement is considered in section I. Section II presents a comprehensive analysis of the indicators and indices discussed in the literature highlighting the inadequacies. Final section concludes.

2. ENERGY SECURITY MEASUREMENT

As there is no accepted definition, there is also no generally accepted methodology to fully assess energy security (Martišauskas et al. 2018; Glynn et al. 2017; Radovanović et al. 2017; Peña Balderrama et al. 2017; Pleßmann & Blechinger 2017; Guivarch & Monjon 2017; Norvaiša & Galinis 2016; Kisel et al. , 2016; Molyneaux et al. 2016; Böhringer & Bortolamedi 2015; Jingzheng & Sovacool 2014; Gracceva & Zeniewski 2014; Mischke & Karlsson 2014; Martchamadol & Kumar 2014; Jewell et al. 2013; Augutis et al. 2012; Sovacool 2012; Kruyt et al. 2009). National energy agencies and international organizations such as IEA (2004, 2007), EECA (2006), NRC (2006), OEERE (2007) and ODYSSEE (2007) have developed measurement and monitoring systems for energy security and performance (Šprajc et al. 2019; Zhou & Ang 2008). Measuring energy security using indicators also allows to monitor the environmental, political, economic and social concerns for sustainable development (Badea, 2010).

For the measurement of energy security the big question arises at the choice of core variables (Šprajc et al. 2019). Even the measurement of these variables of energy security is a challenge. Energy security measurement still remains as a challenge because it does not seem possible to develop a unique model with its components that change over time, from region to region, from country to country (Golušin et al. 2014; Augutis et al. 2012; Umbach 2010; Wang et al. 2009). Relating to the numerous measurement methods and the indicators, energy security measurement is stated to include subjectivity referring to the acceptability of the energy policies (Martišauskas 2018; Molyneaux et al. 2016; Ang et al. 2015; Golušin et al. 2013; Augutis et al. 2012; Wang et al. 2009). Several forms of energy security indices have been suggested so far (Guivarch & Monjon 2017; Cherp et al. 2016; Jewell et al. 2014; Cohen et al. 2011; Lefevre 2010; Loschel 2010a; Jansen & Seebregts 2010; Gupta 2008; O'Leary et al. 2007; Bazillian et al. 2006).

3. INDICATORS/INDICES

Energy security includes numerous factors which make energy security measurement diffucult using a unique indicator. For this reason based on different methods weighted aggregate coefficients such as data envelopment, factor and principal component analysis are established (Radovanović et al. 2017). There are several approaches and methods to measure energy security. As well as the standard measurement models there are also new methods developed specifically for this purpose. Some of these new methods are suggested spesifically at the territorial base. In addition to the production of energy from renewable energy resources, per capita electricity consumption, intensity of carbon, prices of electricity; to measure resilience in terms of energy security; capacity and reserve margins, storage level, flexible demand, efficiency and adequacy are stated as the other indicators considered (Martišauskas et al. 2018; Rose et al. 2018; Erker et al. 2017a, Erker et al. 2017b; Cox 2016; Kisel et al. 2016; Narula & Reddy 2016; Böhringer and Bortolamedi 2015; Cherp & Jewell 2013; GEA 2012; Sovacool 2012; Jewell 2011; Sovacool 2011; Kaufmann et al. 2010; Chaudry et al. 2009). The most common, widely used energy security assessment methods are:

- Dependency on primary energy,
- Dependency on Primary Energy,
- Dependency on External Primary Energy Supply,
- Dependency on Primary Energy Carriers,
- Primary Energy Carrier Dependency,

- Dependency on External Primary Energy Suppliers,
- Composite Supplier Dependency,
- Herfindahl – Hirschmann Index,
- Shannon-Wiener Index,
- Sovereign Credit Ranking,
- Supply/Demand Index for long-term security of supply,
- Oil Vulnerability Index,
- Vulnerability Index,
- Risky External Energy Supply,
- Socio- economic Energy Risk,
- The US Energy Security Risk Index,

International Index of Energy Security Risk,

- MOSES – The IEA Model of Short-term Energy Security,
- Energy Security Index developed by EU Joint Research Center in Italy,
- Energy Architecture Performance Index,

Each of the indicators has pros and cons (Haar & Haar 2019; Martišauskas et al 2018; Guivarch & Monjon 2017; Glynn et al. 2017; Radovanović et al. 2017; Krishnan 2016; Kisel et al. 2016; Bortolamedi 2015; Böhringer & Bortolamedi 2015; Narula & Reddy 2015; Bedendo & Colla 2015; US Chamber of commerce 2011, 2015; Jewell et al. 2014; Böhringer & Samuelson 2014; Frondel & Schmidt 2014; Cherp & Jewell 2013; Cherp et al. 2012; GEA 2012; Cherp 2012; Jewell 2011; Bhattacharyya 2011; Sovacool 2011; Von Hippel et al. 2011; Badea 2010; Stirling 2010; Le Coq and Paltseva 2009; Chaudry et al. 2009; Gnansounou 2008; Suehiro 2008; Kleindorfer, & Saad 2005; Blyth & Lefevre 2004; de Jong et al. 2006; Bohi & Toman 1993):

- Dependency on primary energy

Dependency on primary energy shows the degree of dependence of economic transactions on primary energy as an input. The higher values of the dependency on primary energy means that the economy must be prepared to the unexpected supply and price shocks within the context of cost adjustments (Kruyt et al. 2009; Böhringer & Bortolamedi 2015).

Energy Intensity is the ratio of the total primary energy supply and the gross domestic product:

$$EI = \frac{TPES}{GDP}.$$

(1) TPES total physical primary energy supply

However;

.primary energy dependency of the economy can be underestimated by GDP's primary energy intensity,

.domestic production substitution can improve energy intensity,

.besides purchasing power parities (PPP); currency conversion and market exchange rates (MER) can effect the value of the indicator value.

-Dependency on External Primary Energy Supply

Dependency on external primary energy means dependency on external fossil primary energy resources such as crude oil, natural gas and coal where the governments don't have any control. Basically it shows the fossil primary energy import dependency.

Dependency on External Primary Energy Supply implies the riskiness of the higher levels of imports of fossil primary energy and the use of positive net imports for compensating the deficiency in energy imports by energy exports:

$$\text{NID} = \sum_{ff} \frac{\max(0, M_{ff} - X_{ff})}{\text{TPES}}$$

(2) NID net import dependency
ff fossil primary energy carrier
M_{ff} total imports of fossil primary energy ff
X_{ff} total exports of fossil primary energy ff

-Dependency on Primary Energy Carriers shows the dependence of economic transactions on crude oil, natural gas, coal, renewable energy resources and nuclear which are stated as primary energy carriers. The higher values of the mentioned dependence refers to higher exposures to economic risks related to the mentioned carrier. Higher values of dependency on primary energy carriers means that some of the primary energy carriers are included more referring to higher dependency on the mentioned primary energy carriers.

Dependency on Primary Energy Carriers designates specific primary energy carriers reliance which is risky and is criticized because fuel mix diversity measured by indices based on Herfindahl–Hirschman:

$$\text{PECD} = \sum_{f} \left(\frac{S_f}{\text{TPES}}\right)^2$$

(3) PECD primary energy carrier dependency
$f(S_f)$ total physical supply of primary energy carrier

However;
measuring fuel mix diversity by Herfindahl-Hirschman prevents from distinguishing primary energy alternatives.

-Dependency on External Primary Energy Suppliers shows dependence on single external suppliers. Dependency on external primary energy suppliers takes into consideration the political risk of suppliers and higher values means higher dependency on spesific suppliers.
Depending on a single supplier means higher exposures to economic risks. In order to avoid from supply shocks diversifying the suppliers is a key strategy. Dependency on external primary energy suppliers shows that a single external fossil primary energy supplier means higher price and quantity risks:

$$SD_{ff} = \sum_{i} a_i^{HHI} \left(\frac{\max(0, M_{i,ff} - X_{i,ff})}{\sum_i \max(0, M_{i,ff} - X_{i,ff})}\right)^2 \quad (4)$$

SD Supplier dependency
$M_{i,ff}$ represents fossil primary energy imports coming from supplier i
$X_{i,ff}$ denotes EU's fossil primary energy exports to country i.
a_i^{HHI} supplier specific risk factor

However;
while fossil primary energy suppliers are considered, renewables and nuclear are not considered.

-The Composite Supplier Dependency Composite supplier dependency refers to the aggregation of the external primary energy suppliers. Thus it can be considered as a weighted average.

$$SD = \sum_{ff} \frac{\sum_i \max(0, M_{iff} - X_{iff})}{\sum_{ff} \sum_i \max(0, M_{iff} - X_{iff})} SD_{ff}. \quad (5)$$

However;
supplier fungibility and the risks in the transport are ignored.

-Shannon-Wiener Index and completely supply-oriented Herfindahl-Hirschman Index consider energy security indirectly determining the degree of a spesific country's dependence on a spesific supplier.

Shannon-Wiener Index is maximum when all the shares are equal:

$$SWI = -\sum_{i=1}^{n} p_i \log(p_i) \quad (6)$$

Herfindahl-Hirschman Index is minimum when all the shares are equal:

$$HHI = \sum_{i=1}^{n} p_i^2 \quad (7)$$

-Including the ability of economy to withstand financial and political shocks; one of the basic indicators is Sovereign Credit Rating which affects corporate credit rating of global energy market companies.

-Supply/Demand Index by the Energy Research Centre of the Netherlands (ECN) and Clingendael International Energy Programme (CIEP) is proposed as a European standard deals with transport, supply and demand.

-Oil Vulnerability Index is a composite index that considers certain economic indicators, import dependence and political stability.

-Vulnerability Index is a composite index dealing with the dependency of energy import, intensity of energy, vulnerability of electricity supply, transport fuels nondiversity and the ratio of carbon emissions related to energy in TPES.

-As an entirely supply-oriented indicator considering the level of diversification only; Risky External Energy Supply focuses on the transport safety.

-As a composite index Socio-Economic Energy Risk deals with the GDP, political stability, diversification, availability-feasibility, intensity, transport, dependence and market liquidity.

-Considering geopolitical indicators, economic development, environmental concerns and reliability The US Energy Security Risk Index is a composite index.

-International Index of Energy Security Risk considers expenditure, volatility, intensity, prices, transport, import of fuel, environmental concerns and resources of global fuel.

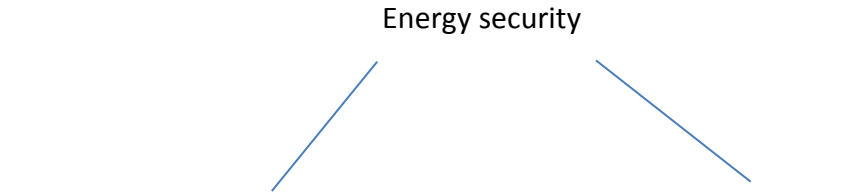
-Including the supply-oriented application of the indicators; The IEA Model of Short-term Energy Security (MOSES) deals with robustness, sovereignty and resilience in the short term and uses data from the World Bank, the IEA, the IAEA and 35 indicators.

-The EU Joint Research Center in Ispra, Italy, considers intensity, carbon, import and production capacity of electricity and transport.

-Energy Architecture Performance Index (EAPI) is proposed by the World Energy Council in 2010 concerning energy and climate policies. Energy Architecture Performance Index (EAPI) was altered to Energy Sustainability Index 2011 with the same approach and methodology and including equity, security, and sustainable environment; Energy Trilemma was developed by the WEC.

The schema shows the dimensions of the trilemma index:

Schema. 1: Dimensions of trilemma index



Source:WEC, 2020**.**

The extensive literature reveals that a unified definition of energy security has been yet to converged to formulate (Glynn et al. 2017). Being a part of national security, energy security is critical for all countries (Downs 2014). Because energy security is such an miscellaneous concept, there are lots of different indicators and indices and this abundance makes it difficult to make consequential aggregation (Böhringer and Bortolamedi 2015; Frondel and Schmidt 2014; Kruyt et al. 2009; Böhringer and Jochem 2007). Besides the indicators are limited in assessing disruptive technological innovation, usually supply oriented and they are insufficient to provide information related to economic costs as they are to respond to unexpected future shocks, shortages and energy crises (Glynn et al. 2017; Böhringer & Bortolamedi 2015; Gracceva & Zeniewski 2014; Sovacool 2013; Cherp & Jewell 2011a; Cherp & Jewell 2011b; Jansen & Seebregts 2010). Energy security assessment instruments are examined within the context of energy security dimensions which are determined as energy supply, demand management, efficiency, economic, environmental, human security, military / security, domestic sociocultural / political, public relations, technological, international and policy (Sovacool 2011; Von Hippel et al. 2009; Vivoda et al. 2010). In order to determine the appropriate indicator/indice it is suggested to consider if the indicator or the indice represents one of the vital energy systems, if it reflects and provides significant vulnerabilities and if there is a continious, reliable data (Cherp & Jewell 2013). The table presents the widely used indices/indicators with the corresponding notations:

Table.1: Indices/indicators and notations

Indice/Indicator	Notation
Energy Intensity	$EI = \frac{TPES}{GDP}$
Dependency on External Primary Energy Supply	$NID = \sum_{ff} \frac{\max(0, M_{ff} - X_{ff})}{TPES}$
Dependency on Primary Energy Carriers	$PECD = \sum_{f} \left(\frac{S_f}{TPES}\right)^2$
Primary Energy Carrier Dependency	
Dependency on External Primary Energy Suppliers	$SD_{ff} = \sum_{i} a_i^{HHI} \left(\frac{\max(0, M_{i,ff} - X_{i,ff})}{\sum_i \max(0, M_{i,ff} - X_{i,ff})} \right)^2$
Composite Supplier Dependency	$SD = \sum_{ff} \frac{\sum_i \max(0, M_{i,ff} - X_{i,ff})}{\sum_{ff} \sum_i \max(0, M_{i,ff} - X_{i,ff})} SD_{ff}$
Herfindahl – Hirschmann Index	$HHI = \sum_{i=1}^{n} p_i^2$
Shannon-Wiener Index	$SWI = -\sum_{i=1}^{n} p_i \log(p_i)$

4. CONCLUSION

Ensuring energy security is the main goal of the energy policies of all countries all over the world because ensuring energy security means ensuring sustainable energy. Energy security needs to be examined from a multidimensional perspective in order to include economic, social, political and environmental concerns. Being associated with renewables and nonrenewable energy resources, fiscal regimes, infrastructure and technology, transportation, energy related carbon dioxide emissions, environmental, social and safety concerns, investment costs, economic, financial and geopolitical constraints, energy security is a too complicated term to have an agreed definition.

Energy security is a global issue and because it is a global issue and because the indicators and indices are used to make international comparisons, to develop and to improve energy policies; the determination of the measurement method matters globally. However there is still not a single and accepted method for energy security measurement.

Indicators and indices are expected to fulfill political, economic, social, geological, environmental and financial interpretations in order to yield trustable comparisons and to make adequate policies. However the accurate measurement of energy security seems almost impossible. Because it is diffucult and sometimes not possible to measure energy security and its components directly, adequately and quantitatively. Thus to have high-quality and reliable data remains as a problem in the field.

Selecting an indicator or an indice is a complicated issue because of the interaction between energy security and its measurement. Even the definition of energy security is controversial and this also contributes the vagueness of the determination of the measurement method. Besides supply of primary energy; resource availability, costs for production, transport, import and power interruption, market conditions, reliability, vulnerability, robustness, resilience regarding to infrastructure, attitudes towards risk, decision making processes under risk and uncertainty, high or volatile prices, cost fluctiations, asymmetric interdependence and consequences for the society are the preliminary priorities to be considers for the policy-makers. Besides the necessity of the multidimensional perspectives it must be conceived that the measurement of energy security has a dynamic characteristics and changes over time as energy security itself.

Evaluating the indicators and indices as quantitative representatives rather than direct measures of energy security may contribute adequate policy making because of their inherent risk referring to the external factors which they are related to. As each indice and indicator has advantages and disadvantages; using aggregated metrics can provide more reliable measurements. Integrated assessment models such as MESSAGE and REMIND can be evaluated in order to get robust data.

Beacuse a uniq measurement method is not possible for energy security and even it were it would not be applicable to every country because of the various economic, social, political, environmental and geological conditions; it is more reasonable to monitor monthly, yearly and seasonal differences.

Energy security measurement is an issue needs to be clarified. Existing measurement methods need to be improved to satisfy real insights. Energy security measurement methods should be updated by current data and should be improved to include expectations to be prepared for the unexpected risks of energy shocks and shortages.

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