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A New Formula to Quantify the National Energy Security of the World's Top Ten Most Populous Nations

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ABSTRACT

Quantification of global sustainable energy security (ES) becomes urgent, but the concepts of ES are still not clear. Thus, this paper is originated from philosophical ES studies, in which the various concepts came from the differences in determining the observed multi-matters (energy, equipment, human, and ecosystem: EPME) and point of view to see the EPME. Therefore, this research is aimed at measuring the EPME variables, producing ES material quantities (Q_{es}). Q_{es} is derived after a 4-stage unification and is defined in a formula. The formula is then applied to calculate the top ten populous nations in the world from 1990 to 2015. Based on the top Q_{es} values, the rankings are Russia (Fed.), USA, Japan, Brazil, China, Indonesia, India, Nigeria, Pakistan, and Bangladesh. The results also highlighted the Q_{es} disparities between nations. A relationship between Q_{es} and National Power Indicator (NPI) was also explored, indicating the ES saturation in the USA and Japan; and the macro energy-policy instability phenomenon in Nigeria. In addition, a comparison of Q_{es} ranking to those of other scholars' results was presented. Finally, the macro sustainable energy policy implication is also highlighted.

Keywords: National Energy Security, Quantification Formula, National Power, Sustainable Energy Policy
JEL Classifications: A12, C43, Q43, Q48

1. INTRODUCTION

Global energy system planning is more urgent, mainly due to global problems, including positive population growth, depletion of energy resources, inefficient energy consumption, energy export-transit-import involving many nations, and especially the threat of catastrophic climate change. In that context, energy security (ES) becomes an essential factor for any nation.

In line with these challenges, intensive ES research has carried out. For examples, ES observation based on historical evaluations for 18 nations spread across four continents (Sovacool et al., 2011), ES for resource-poor economies (Li et al., 2016), and ES for European Union nations have been studied (Matsumoto et al., 2018; Obadi and Korcek, 2020). Besides historical evaluations, a prognosis has also been carried out (Augutis et al., 2017).

Although it has been used for evaluation and prognosis, the concept of ES continues to grow and tends to diverse. The number of scientific publications from year to year has been increased: 8 papers in 2000, 26 papers in 2005, 192 papers in 2010, 317 papers in 2015, and 353 papers in 2017 (Zhou et al., 2018). These publications use different ES concepts.

Since 2010, ES evaluators have been stating that the ES definitions are often diffuse and incoherent, either stated explicitly or implicitly. This unclear meaning could be found after evaluating 45 definitions (Sovacool, 2010), 36 definitions (Winzer, 2012), 83 definitions (Ang et al., 2015). Although they did not formulate a universal definition, they identified some common factors in their focus studies. For examples, the interconnected dimensions (elements) in ES (Sovacool, 2010), the threats to the energy supply chain (Sovacool, 2010; Winzer, 2012), ES dimensions and six specific focus areas (SFA) including Availability - Affordability - Accessibility - Acceptance (4A) (Ang et al., 2015).

The 4A concept was first put forward by the Asia Pacific Energy Research Center (Intharak et al., 2007). Then (Cherp and Jewell, 2014), with the perspective of securities theory, examined the concept of 4A. They concluded that the concept of 4A was unsatisfactory because it did not answer the three basic questions: security for whom, for which values, and from what threats. Therefore, they proposed a new definition. The definition proposed by (Cherp and Jewell, 2014) by (Azzuni and Breyer, 2018) is considered unclear and too general. Thus, they offered a new definition.

To answer why the diversity of ES definitions occurred, an epistemological review of ES phenomena over the last 100 years, has been done (Nelwan et al., 2017). It was concluded that the diverse ES definition is due to the diversity of formal objects (obiectum formale, Lat.), and material objects (obiectum materiale, Lat.). The research revealed that ES material objects consisted of 4 elements: energy-equipment-humans and ecosystems (abbreviated as EPME). So, it is called EPME Concept. So far, EPME involved various formal objects (or scientific points of view): Politics, Geography, Economics, Technology, Ecology, Social, Culture, Military, et cetera.

The material and formal objects need to be integrated if a universal definition is required. Although concept of integration had been suggested explicitly (Cherp and Jewell, 2011) or implicitly (Zhou et al., 2018), the diversity of ES concepts continues (Jakstas, 2020). The conceptual diverseness was also reflected by assessment methods for obtaining ES indicators (Ang et al., 2015; Azzuni and Breyer, 2018; Narula and Reddy, 2015). Thus in the past 20 years, the concept of ES has not been integrated. Therefore, the research of global concept integration is still widely open.

In this research, we propose the development of the EPME quantification method to produce a macro indicator of a nation's ES (Q_{es}). In this case, EPME was observed from the perspective of Technology and Ecology. The observations linked to the national power indicator (NPI), introduced by a political scientist (Beckley, 2018). Because the NPI stated in Macroeconomic indicators, this research is relevant to the discipline of Politics and Economics.

Therefore, the objectives of the present research are to (1) determine the Q_{es} quantification formula, (2) assess the nations' ES performance based on Q_{es}, (3) correlate the relationship between Q_{es} and NPI, (4) determine the relationship between Q_{es} and relevant research results, and (5) recommend the macro ES policy implications.

The results of this research expect to contribute to the academic community in formulating international energy policies. We present contributions in the form of unique information on the development of ES in the ten most populous nations in the world from 1990 to 2015. We also expect that information is useful to determine future international macro energy policies. The other contribution is filling the gap of knowledge in ES Science with an alternative method of quantifying ES conditions.

2. RESEARCH METHODOLOGY

The scientific definition of EPME proposed by (Nelwan et al., 2017), stated: "…energy security is the knowledge of EPME collected from the results of multidisciplinary studies…" Axiologically, this knowledge is useful for enhancing the existence, defense, strength of an entity. In this research, the entity is limited to ten nations.

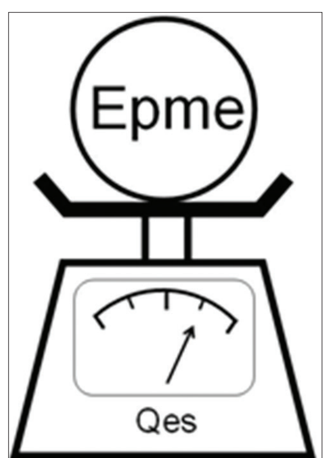
In this section, an attempt had been made to quantify the condition of EPME. Quantification uses the perspective of Technology and Ecology, which ultimately produces numbers with new units. For quantification purposes, the definition was derived into a specific definition or operational definition, which was in line with the method identified by (Ang et al., 2015).

The quantification of EPME is illustrated in Figure 1, where EPME material is placed on a measuring device - symbolized by a weigher.

The amount of EPME, Q_{es}, can be imagined, analogous (but not the same) as the mass of physical objects (matter). Borrowing terms from Macroeconomics, Q_{es} is categorized as a result of macro ES measurement. The amount of EPME, Q_{es}, hypothetically will tend to grow if the wise decisions or policies resulting from the integration of a multidisciplinary perspective are applied.

The EPME quantity, Q_{es}, is a number that is always determined positive because, physically, the elements of EPME are always "exist." The state of the EPME elements is unified into a quantity by a new formula. It will be presented in sub-section 2.2. The EPME unit [Q_{es}], is a unit formed by four elements: energy, equipment, human, and ecosystems. Generate a new unit that is: absolute, unlike the relative dimensional aggregate index - because of the process of normalization as done by (Bogoviz et al., 2019; Erahman et al., 2016; Song et al., 2019; Sovacool et al., 2011) and other scholars. The [Q_{es}] also universal because based on

Figure 1: Illustration of Measurement of the Amount of EPME Material



international units, and new in the sense of not yet suggested in previous research, but abstract as will be explained later.

2.1. Quantification the Elements of EPME

Q_{es} depends on the magnitude of its elements. The higher the value (number) of Q_{es}, indicating the higher the ES core material.

2.1.1. Energy quantity

The amount of energy, E, is the total primary energy supply (TPES) to the national energy system. The selection of TPES, not the total final energy consumption, is based on several arguments. First, historically energy security was about the security of energy supplies (UNECE, 2007). Second, the ES dimension that was considered the most important was the availability or supply of energy in a nation (Ang et al., 2015). Relationship of Q_{es} with E is directly-proportional; the higher E, then Q_{es} will also be increasingly enlarged. So the basics relation are:

$$E = \text{TPES [GJ]} \quad (1)$$

$$Q_{es} \sim E \quad (2)$$

The diversity of energy types will be explored in further research (see section 4).

2.1.2. Equipment quantity

The amount of equipment (p) is the amount that represents technological equipment that takes/processes natural energy into primary energy and then becomes the final energy within a national territory. The equipment is a whole device of exploration, exploitation, refinery, conversion, transmission, distribution, consumption and energy control technology, or equipment for transforming natural energy into primary energy, secondary energy, and tertiary energy or final energy. The technological (Azzuni and Breyer, 2018) or infrastructure (Ang et al., 2015) dimension is relevant to p. Considering the limited availability of global data, then the amount that represents p, is restricted to the capability of technological equipment to transform/convert TPES become final energy. Q_{es} relation with the p is directly-proportional; the higher p, the higher Q_{es}.

$$p = \sum_i p_i \,[\text{GJ}] \quad (3)$$

$$Q_{es} \sim p \quad (4)$$

where i for transformation facilities such as electric power plants, oil refinery, etc. The other properties of the p like reliability, as well as equipment as an economic resource, will measure in further research.

2.1.3. Human quantity

The human (m) magnitude is the number of energy consumers in that nation. So, m is limited to the number of people or population. Because m viewed as a consumer (not a producer), the mathematical relationship Q_{es} with m is inversely-proportional (not directly-proportional); so the more m, the lower Q_{es} (not higher).

$$m = \text{Population [Capita]} \quad (5)$$

$$Q_{es} \sim \frac{1}{m} \quad (6)$$

There are a lot of magnitudes related to a large number of people gathered in one nation suchlike as qualities involving values, norms, energy-saving culture, productivity, creativity (innovation), even energy justice (Sovacool et al., 2017). It will measure at further research. Also, the quantification of the effect of a small portion m as a regulator (or producer) of E is necessary to calculate.

2.1.4. Ecosystem quantity

The ecosystem element, e, represents by the quantity of energy emission and CO_2 emission that is produced by the energy system, which thrown back to the ecosystem as a waste. Energy emission (e_1) increases the ambient entropy, and CO_2 emission (e_2) will raise the global warming phenomenon or global catastrophic climate change. Of the many greenhouse gases, CO_2 chose, because based on 2006 IPCC Guidelines for National Greenhouse Gas Inventories – (IPCC, 2006), that: (1) gas emission from the energy sector, 95% in the form of CO_2, (2) the energy sector contributes typically 90% of total CO_2. This element is relevant to the environment dimension (Ang et al., 2015; Azzuni and Breyer, 2018).

Q_{es} will increase when: (1) e_1 decreases (reduce), (2) e_2 decreases, Q_{es} will increase. So the equation of the relation Q_{es} with e_1 and e_2:

$$e = f\,(e_1, e_2) \quad (7)$$

$$Q_{es} \sim (-e_1) \quad (8)$$

$$Q_{es} \sim \frac{1}{e_2} \quad (9)$$

where the units of e_1 in [GJ], and e_2 in 1000 [kg CO_2] or [tCO_2].

2.2. Formulating Q_{es}

The Q_{es} formulation states the whole process: energy supply (E) is transformed by equipment (p) to meet human consumption (m) either direct or in-direct. Some of the energy that converted loosen back to the ecosystem (e), as an emissions energy (e_1) and CO_2 emission (e_2). The whole process wants to be unified (condensed) into one number as a macro indicator for the national energy security condition.

So, mathematically start from equation (10).

$$Q_{es} = f\,(E, p, m, e_1, e_2) \quad (10)$$

The unification process of 5 variables quantities carried out with the following steps. First, to states that without p, the E as the public commodity cannot be consumed by m, either direct or indirect. E transformed by p, the E value will multiply. Therefore, E and p unified with multiplication operations, not a summation. Refer to equations (2) and (4), Q_{es} become:

$$Q_{es}\,(E, p) = E.p \,[\text{GJ}^2] \quad (11)$$

Looking at the unit of Q_{es} (E,p) in [GJ^2] - it appears that it no longer states a real physical-material unit; it is an abstract unit. In order not to confuse the real physics unit, we define a unique unit in the field of Energy Security, namely Joule Energy Security, abbreviated as [J_{es}], where:

$$1\ [J_{es}] = 1\ [GJ^2] \quad (12)$$

Refer to formula (11); if E and p = 1 [GJ], then the Q_{es} (E,p) = 1 [J_{es}]. It defined as unit strength. If "E.p" in a nation equals to 71 [PJ_{es}], then total strength in that nation is 71 [PJ_{es}]. Therefore, E.p is called the total strength of ES (ESS), which is given the symbol S. Suppose E and p are atoms, then ESS is a compound.

Second, the unification of the Q_{es} (E,p) with m is carried out by the division arithmetic operation. It means ESS is ultimately distributed both direct and in-direct to consumers m at various sectors: industry, transportation, residential, commercial, etc. Referring to equations (6), (11) and (12) the second unification results:

$$Q_{es}(E,p,m) = \frac{E.p}{m}\left[Jes / Capita\right] \quad (13)$$

ESS divided by the number of population defined as the average of ES-strength (ESs) given the symbol s. ESs is a compound too.

Third, the unification of e_1 with Q_{es} (E,p,m) is done by reducing e_1 to E. Referring to equations (8) and (13), resulting:

$$Q_{es}(E,p,m,e_1) = \frac{(E\text{-}e_1).p}{m}\left[J_{es} / Capita\right] \quad (14)$$

Equation (14) states that ESs (and also Q_{es}) will decrease if e_1 enlarges. The higher e_1 means the rejected energy as waste energy into the ecosystem, become enlarger. Physically, (E-e_1) is the same as useful energy. So Q_{es} (E,p,m,e_1) defined as: 'Useful ESs' (UESs) compounds. Fourth, unification e_2 with the Q_{es} (E,p,m,e_1) is carried out by division operation. Refer to equations (9) and (14), resulting in core formula:

$$Q_{es}(E,p,m,e_1,e_2) = \frac{\frac{(E\text{-}e_1).p}{m}}{e_2}\left[\frac{Jes / Capita}{tCO_2}\right] \quad (15)$$

Equation (15) states e_2 as the ultimate constraint to maximizing UESs (and also Q_{es}). The more e_2 produced, the higher impact on global warming and increase the climate change catastrophic risk. It has become a threat to national and global sustainable development. The EPME Concept strengthens global sustainable development on earth. The Q_{es} unit named a new term: [Esse], an evocative acronym for energy security for a sustainable earth. So that:

$$1\left[\frac{Jes/Capita}{tCO_2}\right] = 1\ \left[Esse\right] \quad (16)$$

At this point, the process of unifying five core variables has produced the core formula (15). Some variations of the core formula will state in the next related sub-section.

2.3. Data: Source and Processing Method

The present research is about involving the top ten populous nations in the world: China, India, USA, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russian Federation, and Japan. It reaches around 58% of the world's population. Observations made from 1990 to 2015.

E data stated by TPES obtained from Energy Balance (EB) issued by the International Energy Agency (IEA, 2019). If the TPES data quoted without needing to be processed, then the "p" data for each nation, needs to be processed using the formula:

$$p = \sum_{i=1}^{8} p_i \left[GJ\right] \quad (17)$$

where, i for each transformation facilities: (1) Electricity plants, (2) CHP (combined heat and power) plants, (3) heat plants, (4) gas works, (5) oil refineries, (6) coal transformation, (7) liquefaction plants, (8) other transformation. Data p obtained from EB-IEA (IEA, 2019). The population data (m) quoted from the United Nations Population Division (UN, 2018).

Data e_1 is obtained by summing: energy emissions in the process of transforming primary energy into final energy (e_{11}), with energy emissions in the transformation process of final energy into useful energy (e_{12}):

$$e_1 = e_{11} + e_{12}\ [GJ] \quad (18)$$

$$e_{11} = \sum_{j=1}^{7} (E_{input} \text{-} E_{output})_j \left[GJ\right] \quad (19)$$

where j for each transformation facilities, are: (1) Electricity plants, (2) CHP plants, (3) heat plants, (4) gas works, (5) oil refineries, (6) liquefaction plants, (7) transmission and distribution. Data E_{input} and E_{output} each facility cited from (IEA, 2019). Data e_{11} is converted to efficiency primary to final energy (η_{pf}):

$$\eta_{pf} = \frac{E - e_{11}}{E} 100\left[\%\right] \quad (20)$$

where, E is TPES, (E-e_{11}) is the final energy. Knowing final to useful energy efficiency (η_{fu}) then can get primary to useful energy efficiency η_{pu} (or overall energy efficiency):

$$\eta_{pu} = \eta_{pf}.\eta_{fu}\ [\%] \quad (21)$$

Using the value η_{pu}, then e_1 can be determined:

$$e_1 = \left(1\text{-}\eta_{pu}\right)E\ \left[GJ\right] \quad (22)$$

These steps, (18)-(22), were carried out because, as far as our efforts, e_1 data for ten countries from 1990 to 2015 not found from one source. Indeed, the Lawrence Livermore National Laboratory (LLNL), in collaboration with the US Department of Energy (DOE) publishes an energy flow chart (Sankey chart) that contains data (e_1) and ($E-e_1$) for many nations (LLNL, 2019). But published data use the assumption that η_{fu} of the consumption sector in 9 countries is almost the same as the USA. Differences are only caused by decimal rounding and statistical differences. Indeed, (Zhang et al., 2011) published estimates related to e_{12} for 1990-2009, but only for China in the transportation and residential consumption sector. Likewise, (Amoo and Fagbenle, 2014) published the estimation, which is related to e_{12} for 1988-2009, but only for Nigeria in the transportation consumption sector. Also, other research results (about efficiency) only concern one nation and one-two consumptions sector. Finally, we cite efficiency data reported by Professor Nakicenovic and colleagues in several scientific publications. For η_{fu} in 1990 (Gilli et al., 1995; Nakićenović et al., 1996), and η_{fu} in 2005 (Johansson et al., 2012). After knowing η_{fu}, using (20) and (21), η_{pu} was obtained for 1990 and 2005. Then η_{fu} for 2015, was calculated using formula (23), assuming the η_{pu} curve from 1990 to 2015 is linear, obtained:

$$\eta_{pu(t_3)} = \eta_{pu}(t_2) + \frac{\eta_{pu}(t_2) - \eta_{pu}(t_1)}{t_2 - t_1}(t_3 - t_2) \quad (23)$$

where, t_1 for 1990, t_2 for 2005 and t_3 for 2015. Linear assumptions had made after studying the results of research (Ayres et al., 2003). It revealed the 1900-1998 energy (exergy) efficiency curve for the USA, where the 25-year curve, in general, tends to form a straight line. Assumption strengthened after studying research results, among others (Badmus and Osunleke, 2010; Chowdhury et al., 2019; Chowdhury et al., 2020; Kondo, 2009; Mitra and Gautam, 2014), regarding other efficiencies. The estimation results using formula (23) are then compared with the results of historical efficiency improvements on average: 1 [%/year] (Gilli et al., 1995). Know η_{pu}, e_1 can compute by the formula (22), and vice versa.

CO_2 (e_2) emissions consist of 2 components: (1) emissions from fossil energy (e_{21}), (2) reduction by fossil carbon capture and storage (CCS) (e_{22}):

$$e_2 = e_{21} - e_{22} \; [tCO_2] \quad (24)$$

The e_{21} data quoted from European Commission-Joint Research Centre-Emission Database for Global Atmospheric Research (EDGAR) (Crippa et al., 2019). EDGAR estimates e_{21} based on EB-IEA data. CO_2 reduction by carbon capture and storage facilities data, quoted from the Global Carbon Capture and Storage Institute (GCCSI, 2015).

2.4. Beckley Method

Historically-ontologically, the concept of ES was born before World War I (Yergin, 2006). Since then, ES has become an important element in national power. Therefore, an examination of the relationship between Qes and the national power indicator (NPI) was carried out. The new NPI calculation method discovered by Michael Beckley (Beckley, 2018). Beckley formulated NPI by explaining that GDP as a macroeconomic and military indicator and GDP/capita is a rough- indicator of economic and military efficiency:

$$NPI = \frac{GDP \times GDP}{Capita} \quad (25)$$

Beckley has demonstrated, conclusively, that the NPI (25) can explain the superiority of a nation in competition between nations, from 1839 to 2015.

The NPI, calculated using the formula (25), and using GDP-PPP data (constant 2011 USD) quoted from the World Bank (WB, 2019). Whereas population data from the UN Population Division (UN, 2018). The relationship between Q_{es} and national power indicator (NPI) examined by calculating the correlation coefficient using the Pearson linear method (Dowdy et al., 2004).

2.5. Rank Comparison Method (RCM)

RCM is useful for comparing 2 ES rankings, each of which applies different ES concepts and quantification methods. For explanation here, the results of the research (Sovacool et al., 2011) called ES performance (ESP), are taken as a comparison. ESP ranking (covers 18 nations) compared to Q_{es} ranking (covers 10 nations).

The RCM consists of 4 steps. First, the suitability of the assessed nation examined. It turns out that only five nations were suitable, namely: the USA, Japan, Indonesia, China, and India. Second, the ESP ranking number (original) is 1. Japan, 3. USA, 11. Indonesia, 14. China, 17. India; modified to 1. Japan, 2. USA, 3. Indonesia, 4. China, 5. India. Even though the ranking number modified, the rank order has not changed, for example, Japan remains above the USA. Likewise, the ranking number on Q_{es} is modified too. Third, the rank correlation coefficient (r) determined with the Spearman method (Dowdy et al., 2004). Fourth, after r is known, a qualitative check performed to answer why the r values occur.

3. RESULTS AND DISCUSSION

These results: the quantification formula, the performance of ten countries from 1990 to 2015, the correlation between ESs (also Q_{es}) and NPI, and the comparison of Q_{es} with other scholar results, are explained and discussed in this section. Also, another point of view, especially Economics, for further research briefly explained.

3.1. Formula Results and Discussion

The formula results will be separated into several compounds to obtain more results and more in-depth discussion material. Also, with simple terms, abbreviations, and symbols. Combine the formulas (15) and (16), then formula (26) is generated:

$$Q_{es} = \frac{(E-e_1).p}{m.e_2}[Esse] \quad (26)$$

The formula (26) is also an operational definition to know the EPME condition quantitatively, which when formulated in a definitive sentence, is: primary energy supply (E) flows continuously through a set of conversion/transformation technology (p) so that it can be consumed either directly or indirectly by humans (m); always produce emission waste (e_1 and e_2) which harm the ecosystem (e), which in the medium and long term will threaten the continuity of the flow of E to p and especially to m in the nation; finally throughout the world.

The formula (26) shows that to increase the Q_{es} value is by reducing CO_2 emission, such as the intensification of non-carbon energy resources like hydropower, solar PV, wind power, geothermal, and nuclear. The formula (26) also shows the importance of CO_2 emission reduction to mitigate climate change disaster. The risk of catastrophic climate change is increasing because, in reality, the global facts show that CO_2 emissions from burning fuel continued to enlarge in 2000-2017 (IEA, 2020a).

The Q_{es} unit, [Esse], is an abstract unit, meaning that Q_{es} represents an abstract ES. It is suited to ES as an abstract concept (Jakstas, 2020). Although Q_{es} is abstract, it could be interpreted as a real one. For example, if Q_{es} of Brazil rises from 160 [Esse] to 351 [Esse], it could be interpreted that Brazil's ES is getting better. And further, it could be interpreted that its macro energy policy is in the right direction.

Rewrite formula (13) in terms of ESs (s):

$$ESs = s = \frac{E.p}{m}\left[Jes / Capita\right] \quad (27)$$

Furthermore, referring to formulas (26) and (27), formula (28) can be generated,

$$Q_{es} = \frac{s}{(e_2.E)/(E\text{-}e_1)}\left[Esse\right] \quad (28)$$

Then the denominator, symbolized by the letter w, becomes:

$$w = \frac{e_2.E}{E\text{-}e_1}\left[\frac{GJ.tCO_2}{GJ}\right] \quad (29)$$

where w for waste. So, the term for w is ES-waste (ESw) compounds. Define a new unit for w:

$$1\left[\frac{GJ.tCO_2}{GJ}\right] = 1\left[W_{es}\right] \quad (30)$$

where W_{es} stands for waste energy security.

Remembering the primary to useful energy or overall efficiency (η_{pu}) as (31), then the formula (29) becomes (32):

$$\eta_{pu} = \frac{E - e_1}{E}100\ \left[\%\right] \quad (31)$$

$$ESw = w = \frac{e_2}{\eta_{pu}}\left[W_{es}\right] \quad (32)$$

Setting w in η_{pu} will be more flexible than using the e1 variable, in the effort to develop methods. Energy Economics combines energy efficiency with the energy effectiveness produces an indicator: energy intensity, which is used by (Brown et al., 2014; Pysar, 2019; Sharifuddin, 2014), as well as many other scholars. Next, the formula (26), when stated in s and w, becomes a much simpler formula:

$$Q_{es} = \frac{s}{w}\left[Esse\right] \quad (33)$$

where s stands for ESs, and w stands for ESw.

3.2. Energy Security Strength

This sub-section contains ESS compounds, ESs compounds, and ESs correlation to National Power Indicator (NPI). Each part discus the conditions of 10 nations in 1990-2015.

3.2.1. Total strength (ESS)

ESS calculated using equation (11), resulting in Table 1. ESS=71 [PJ_{es}] for Bangladesh at 1990, match with the nation's ability to secure primary energy supply (E) and to secure the capability of primary energy processing equipment (p) to final energy around 543.106 [GJ] and 130.106 [GJ] (IEA, 2019) respectively. Looking at the E and p numbers, revealed that around 76% of E, did not pass through p. Most of the 76% is solid biofuel for the residential sector (IEA, 2020b). This fact signifies ESS of Bangladesh in 1990, relatively low because the majority of E is solid biofuel (traditional biomass). It was related to the problem of energy poverty (González-Eguino, 2015). Table 1 shows that until 2010 the USA had first ranked after that surpassed China. So in 2015, China was ranked first, followed consecutively: USA, India, Russia, Japan, Brazil, Indonesia, Pakistan, Nigeria, and Bangladesh. China has succeeded in enlarging ESS about 21 times: from 487,958 [PJ_{es}] at 1990 to 10,478,518 [PJ_{es}] at 2015. China, India, Indonesia, Brazil, Pakistan, and Bangladesh have always grown positively from 1990 to 2015.

While the USA, Nigeria, Japan, and Russia fluctuated. The USA initially grew positively until 2005, then negatively. Nigeria initially grew negatively until 2000, then turned positive. Russia grew negatively from 1990 to 2000, after that, it was positive. Until 2005, Japan grew positively, but after that, it experienced negative growth.

ESS for six nations tends to increase, four nations fluctuated. Inward looking, of course, caused by internal EPME variables: E and p, where E and p influenced by human (m) needs in that nation. Outward looking, of course, there are external variables that lead to the achievement of national ESS, for example, foreign investment security, which preceded by national, regional, and global political stability.

3.2.2. Average strength [ESs]

Table 2 and Figure 2 show the ESs (ESS divided by the total population) results. Figure 2 displays the 1990-2015 ESs with a logarithmic scale to shorten the vertical distance (y-axis). It also displayed the nation ranking in 2015. It appears that the USA has been in the top ranking continuously for 25 years. China, which in 1990 was ranked 4th, surpassed Japan in 2010 and then Russia

Table 1: Energy security strength (ESS) 1990-2015, in [PJ_{es}]

Nations	1990	1995	2000	2005	2010	2015
China	487,958	873,631	1,259,450	3,278,886	6,935,103	10,478,518
India	69,358	114,342	199,872	291,991	589,869	882,151
USA	5,284,290	6,191,852	7,477,364	7,646,133	7,106,330	6,953,540
Indonesia	7,248	15,084	22,728	29,054	38,096	47,681
Brazil	24,232	30,344	45,612	58,781	80,175	103,726
Pakistan	1,108	1,767	2,735	4,052	4,394	5,779
Nigeria	2,081	1,848	1,749	3,660	3,924	4,414
Bangladesh	71	124	178	312	627	1,037
Russia	1,236,479	647,859	611,141	665,065	799,856	823,781
Japan	310,029	405,609	438,499	445,824	405,795	297,647

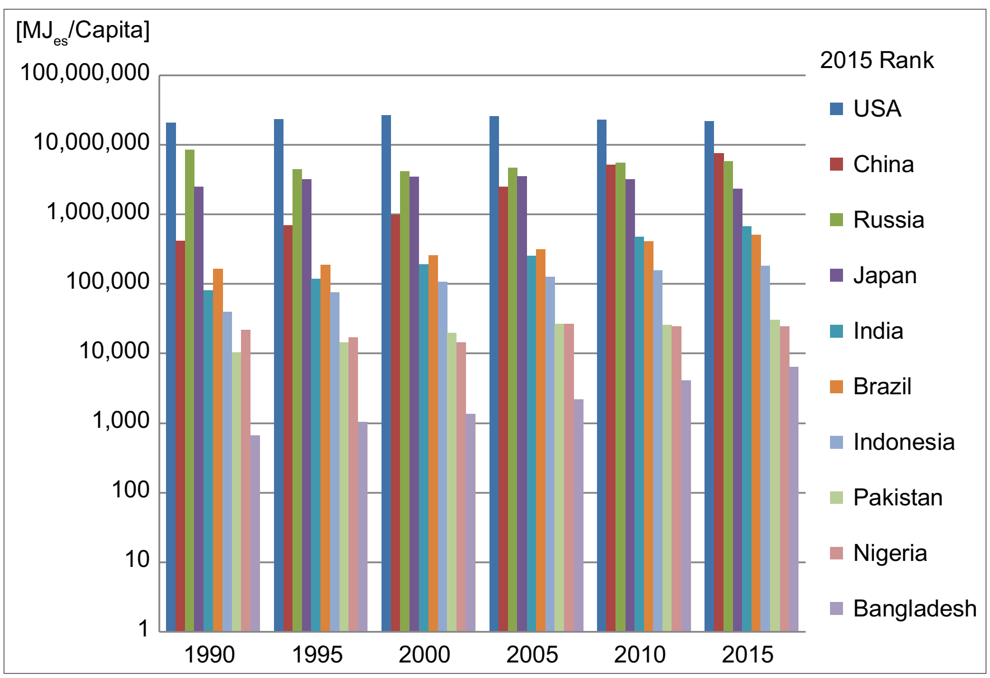
Source: Processed from Energy Balances Data (IEA, 2019)

Table 2: Energy security average strength (ESs) 1990-2015, in [MJ_{es}/Capita]

Nations	1990	1995	2000	2005	2010	2015
China	416,188	704,576	981,492	2,480,953	5,100,259	7,500,576
India	79,710	119,047	189,803	255,211	479,186	673,884
USA	20,925,399	23,307,530	26,517,094	25,907,721	23,024,551	21,734,624
Indonesia	39,949	76,584	107,439	128,155	157,082	184,696
Brazil	162,249	186,964	260,210	314,476	407,400	503,618
Pakistan	10,286	14,389	19,747	26,325	25,761	30,516
Nigeria	21,843	17,106	14,294	26,344	24,744	24,365
Bangladesh	665	1,044	1,352	2,176	4,120	6,436
Russia	8,379,270	4,368,901	4,174,560	4,630,785	5,587,389	5,725,153
Japan	2,489,878	3,209,558	3,438,297	3,473,887	3,156,664	2,325,822

Source: Processed from Energy Balances Data (IEA, 2019), and World Population Data (UN., 2018)

Figure 2: ES average strength, 1990-2015 in [MJes/Capita], log scale



Source: Processed from EB Data (IEA, 2019), and World Population Data (UN, 2018)

in 2015. Likewise, India, from rank 6 in 1990, succeeded in surpassing Brazil in 2010. It means that in the period 1990-2015, China and India managed to rise in rank, while Russia, Japan, and Brazil are dropped in rank; meanwhile, the USA, Indonesia, Nigeria, Pakistan, and Bangladesh remain ranked: 1, 7, 8, 9 and 10. These results indicate that large ESs growth occurred in 7 nations, while three nations (USA, Russia, and Japan) experienced small, even negative growths, in the period 1990-2015.

Examining the growth of ESs for 5 years revealed the phenomenon of negative growth in nations: the USA in the range 2000-2005-2010, Russia in the range 1990-1995-2000, and Japan experienced negative growth in the range of 2005-2010-2015. While 6 other nations, always positive. Especially for Nigeria, experienced dynamic fluctuations: negative in the range 1990-1995-2000, then 2000-2005-2010 positive, then 2010-2015 negative; gives a strong indication of the instability of macro energy policies from 1990 to 2015 in Nigeria.

ESs is stable or not, caused by the internal variables E,p, and m. Outward looking, there are external variables that affect the achievement of national ESs. Among others, the variable of the nation's interaction between exporters and importers E and or p. Which, based on nations' sovereignty, which is a Political Science, International Relations, and Security Studies research field (Cherp and Jewell, 2011). National Sovereignty is one of the external variables in the EPME Concept.

3.2.3. Relation ESs and NPI

Comparing the formula ESs (27) with NPI (25), it appears that there are at least two similarities between ESs and NPI: (1) formula structure, and (2) abstract measurement units. The abstract unit of measurement, not explicitly stated by Beckley in his paper but rather implicitly. The NPI unit [USD2/Capita], disappear as a result of a division/comparison operation between the two nations (Beckley, 2018).

Table 3 shows NPI, which calculated using the formula (25), with PPP GDP data sourced from the World Bank (WB, 2019) and total population from United Nations Population Division (UN., 2018). It appears that NPI USA is always at the top during the observation period.

The linear Pearson method is used to calculate the relationship between NPI and ESs in each nation. Calculations are made for a period: 1990-2000 and 2000-2015. The NPI correlation coefficient with ESs, for the period 1990-2000, shows that 9 nations have a very strong correlation because it has coefficients: +0.891 to +1.000; only Nigeria has a weak and negative correlation. While for the period 2000-2015, 9 nations showed a very strong correlation (both positive and negative), only Nigeria showed a moderate correlation (+0.608). The 'anomaly' in Nigeria reinforces the allegations about the instability of macro energy policies, as stated in the ESs discussion (section 3.2.2).

In the period 2000-2015, a strong but negative correlation was revealed in the USA and Japan, where the increase in NPI was accompanied by a decrease in ESs. This phenomenon can be interpreted that: USA and Japan have exceeded-the maximum limit. The USA and Japan have different maximum ESs: the USA at 26.5 [TJes/Capita] in 2000; and Japan at 3.5 [TJes/Capita] in 2005. So it should be suspected of the optimum number of ESs that are typical for developed nations. And if the optimum number has not been reached, the correlation between NPI and ESs tends to strong and positive.

So it can be concluded that NPI with ESs (and also Q_{es}) generally has a strong correlation over a certain period. So it can also be stated that the NPI-Beckley concept has a strong correlation with the EPME Concept. Because NPI is stated in the quantity of Macroeconomics, EPME related to Economics also. Between NPI and Qes, which one is the independent and dependent variable, will be examined later on.

3.3. Energy Security Waste (ESW)

ESw (w) is relevant to the environment and sustainable energy concepts, either nationally or globally. Due to the limitations of e12 (emission in final to useful energy transformation) data for ten nations, observations only made for 1990, 2005, and 2015.

3.3.1. Energy emissions

Energy emissions (e_1) after being transformed by formula (31) can be expressed as primary to useful energy efficiency (ηpu). Table 4 shows ηpu of 34.9% for Russia in 1990. This also means that 65.1% of the total primary energy supply is wasted in the ecosystem. But in 2005, Russia's ηpu increased to 48.8% and then to 58.2% in 2015. This means that Russia has significantly improved technical efficiency. Likewise, with other nations. Only the USA experienced a decline from 1990-2005-2015: 47.3% - 40.9% - 36.6%, respectively. For comparison, η_{pu} for the USA in 2015, based on data published by Lawrence Livermore National Laboratory with the US Department of Energy (LLNL, 2019), then we calculate, producing about 32%. It means that our estimate is 4.6% higher.

3.3.2. CO_2 emissions

The estimated CO_2 emission (e_2) is displayed in Table 5. It appears that e_2 increased from 1990 to 2005 for all nations except Russia. Then from 2005 to 2015, almost all nations increased, except the USA and Japan. The decline in the USA since 2005-2015 was also caused by the presence of carbon capture and storage (CCS) facilities. Although there was still very little capacity, which was around 9 and 20 [$MtCO_2$] in 2005 and 2015 (GCCSI,

Table 3: National power indicator 1990-2015 in 10^{15} [USD^2/Capita], 2015 NPI rank and coefficient of correlation between NPI and ESs

Nations	1990	1995	2000	2005	2010	2015	Rank	Coeffient of correlation	
							2015	1990-2000	2000-2015
China	2.5	7.7	16.9	41.8	118.7	246.6	2	0.984	0.978
India	3.2	4.7	7.8	13.4	24.5	43.3	6	1.000	0.989
USA	334.4	409.5	588.7	725.4	759.0	909.7	1	0.989	−0.904
Indonesia	3.9	7.1	7.1	10.6	17.2	27.7	7	0.891	0.985
Brazil	15.9	19.8	22.7	28.3	41.6	44.5	5	0.934	0.966
Pakistan	1.0	1.4	1.7	2.5	3.1	4.2	9	0.991	0.935
Nigeria	1.1	1.0	1.2	2.4	4.1	5.9	8	−0.273	0.608
Bangladesh	0.2	0.2	0.4	0.5	0.9	1.6	10	0.982	0.995
Russia	64.9	24.9	29.5	54.6	77.6	90.5	4	0.989	0.982
Japan	114.6	130.9	144.7	161.8	163.1	180.8	3	0.970	−0.865

Source: Processed from GDP PPP Data (WB, 2019), and World Population Data (UN, 2018)

2015). Emissions of 10,821 [$MtCO_2$] in 2015 made China the largest emitter, followed by the USA, India, Russia, Japan, Brazil, Indonesia, Pakistan, Nigeria, and Bangladesh.

3.3.3. Combination of energy and CO_2 emission

The combination of energy emissions and CO_2 emissions forms ESw (ESw), as shown in Table 6. It can be stated that: Brazil, Nigeria, Russia, and Japan succeeded in reducing waste emissions. This indicates the consistency and effectiveness of macro energy policies in the 4 nations in suppressing ESw from 1990 to 2015. The USA succeeded in suppressing ESw from 2005 to 2015, whereas five other nations: China, India, Indonesia, Pakistan, and Bangladesh, showed a tendency to increase from 1990 to 2015.

3.4. Quantity of ES (Q_{es})

Quantity of ES (Q_{es}) had obtained by substituting the ESs and the ESw values to formula (33). Table 7 shows that the overall average Q_{es} tends to increase due to the performance of 8 nations: China, India, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russia. The USA experienced a continuous decrease and Japan dropped in 2015.

Figure 3 shows the Q_{es} ranking in 2015. From that figure, it is clear that the performance of the USA tends to decrease so that Russia can be surpassed by 2015. Why did Q_{es} USA surpass Russia in 2015? The causes are as following: first, the ESs of Russia increased while the USA dropped. Second, the decrease in ESw of Russia was higher than the decrease in the USA. As a result, in 2015, Q_{es} Russia blossomed 141%, the USA shrank 14% compared to 2005.

From the Q_{es} ratio number (r_Q) in Table 7, it appears that China's Q_{es} in 2015 grew 8 times compared to 1990. Conversely, the USA was 78%, which is the same as 22% shrinkage. The other 7 countries have more than doubled in size, while Nigeria has only 153%. If the USA ratio continues to decline, and if the China ratio figure remains 801% in the next 25 years, China may surpass the USA before 2040. This prognosis is very rough, needs to be refined through other research, which is more in-depth about the interaction of internal and external variables.

Figure 3: Quantity of energy security (Qes), 1990-2015

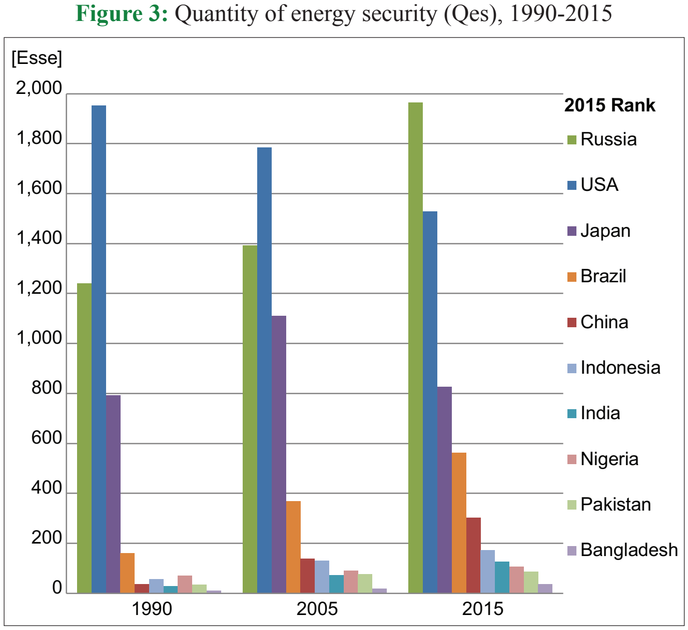


Table 4: Estimated efficiency, in [%]

Nations	1990	2005	2015
China	21.7	34.8	43.6
India	21.4	34.2	42.7
USA	47.3	40.9	36.6
Indonesia	23.0	36.7	45.8
Brazil	22.6	44.6	59.2
Pakistan	22.1	37.8	48.3
Nigeria	24.1	35.2	42.7
Bangladesh	21.7	35.8	45.1
Russia	34.9	48.8	58.2
Japan	36.6	40.8	43.7

Source: Processed from EB Data (IEA, 2019), 1990 Data (Gilli et al., 1995; Nakićenović et al., 1996), and 2005 Data (Johansson et al., 2012)

Table 5: Estimated CO_2 emissions, 1990-2015, in [$MtCO_2$]

Nations	1990	2005	2015
China	2,398	6,265	10,821
India	595	1,211	2,287
USA	5,064	5,938	5,205
Indonesia	163	360	489
Brazil	229	381	529
Pakistan	64	130	168
Nigeria	75	101	97
Bangladesh	14	39	80
Russia	2,355	1,623	1,694
Japan	1,149	1,277	1,228

Source: EDGAR EU-JRC (Crippa et al., 2019)

Table 6: Energy Security Waste (ESw), 1990-2005-2015, in [MW_{es}]

Nations	1990	2005	2015	r_w
China	11,030	17,980	24,830	225
India	2,783	3,542	5,353	192
USA	10,710	14,523	14,214	133
Indonesia	707	982	1,069	151
Brazil	1,011	855	894	88
Pakistan	291	345	348	120
Nigeria	310	288	226	73
Bangladesh	64	109	177	278
Russia	6,756	3,323	2,914	43
Japan	3,143	3,127	2,812	89

r_w: the ratio of w values at 2015 over 1990, [%]

Table 7: Quantity of energy security (Q_{es})

Nations	1990	2005	2015	r_Q
	[Esse]	[Esse]	[Esse]	[%]
China	38	138	302	801
India	29	72	126	439
USA	1,954	1,784	1,529	78
Indonesia	56	130	173	306
Brazil	160	368	564	351
Pakistan	35	76	88	248
Nigeria	70	92	108	153
Bangladesh	10	20	36	348
Russia	1,240	1,393	1,965	158
Japan	792	1,111	827	104
Mean	439	518	572	

Esse: ES unit, r_Q: Q_{es} ratio between 2015 and 1990 [%]

Furthermore, by pulling two benchmark numbers of 100 and 700 [Esse], the ten assessed nations will be divided into three groups: (1) High-level nation, during the year of observation consisting of the USA, Russia, and Japan, (2) Middle-level nation, initially only consist of Brazil, then China, Indonesia, and then India followed in 2015, and (3) Low-level nation, initially consist of 6 nations, then decreased by 2 nations in 2005, and then 2 more in 2015. Pakistan and Bangladesh remain at a low-level; despite showing improved performance.

The Q_{es} ratio between nations in 1 year provides significant information, as it shows ES disparity between nations. In 1990, the ratio of rank 1 to rank 10 was 195:1, in 2005, it dropped to 89:1, and then in 2015, it dropped to 55:1, respectively. These numbers show that disparity is getting lower, and is a relative number. But in absolute terms, it shows a clear real inequality. This inequality is clearly shown in Figure 3, where the figure was not changed on the logarithmic scale, as it was in Figure 2.

The disparity became disguised and disappeared if the normalization in the aggregation process was done. For example, the normalization method used by (Erahman et al., 2016) resulted that the USA scores in 2008 and 2013 were 0.781 and 0.802 respectively; and Bangladesh scores in 2008 and 2013 were: 0.356 and 0.342 respectively. A comparison between the USA and Bangladesh scores yields a ratio of 2.1:1 and 2.3:1. The normalization method, while a widely used method, does not produce a proportional ES quantity of disparity between nations.

The problem of disparity is evident in that the Russia-USA-Japan Q_{es} value was far superior to that of the Bangladesh-Nigeria-Pakistan. When compared to the value of ESw, Bangladesh-Nigeria-Pakistan is more superior to Russia-USA-Japan. Therefore, to reduce the disparity of Q_{es} and ESw, it is proposed the synergistic cooperation. The form of the cooperation program, for example, has been proposed by (González-Eguino, 2015), namely the improvement of modern energy infrastructure, so that health problems due to the use of traditional biomass are significantly reduced. More specifically, we propose a collaboration (mutually beneficial) to improve traditional biomass processing infrastructure into modern biomass (biofuel). In other terms, it is pertaining to a reduction of global energy poverty.

3.5. Comparison to Other Research

This section refers to section 2.5. about the Rank Comparison Method. The ES performance (ESP) of 18 nations, including China, India, USA, Indonesia, and Japan, for the years 1990-2010 was reported by (Sovacool et al., 2011). The modified Q_{es} and ESP rank shows in Table 8.

Using the Spearman method, obtained the correlation coefficient, r = +0.6 (moderate relationship) in the year 1990, and r = +0.8 (strong relationship) in the year 2005. The increase in r due to an increase in the number of indicators used by ESP. In the year 1990, ESP used 15 indicators, while in the year 2005 used 20 indicators. From this case, it concluded that the more indicators used by ESP, the stronger relationship between Q_{es} an ESP relationship.

The ES Index (ESI) for the 6 years of 2008-2013 was reported by (Erahman et al., 2016) for 71 nations. The ESI involves 14 indicators. There were differences in the years of observation, making the comparison could only be made between the closest years: 2005 to 2008, and 2013 to 2015. Table 9 shows the Q_{es} and ESI modified-rank.

Using the Spearman method, obtained the correlation coefficient (r) between Q_{es} (2005) and ESI (2008) of +0.94 (very strong relationship); and between Q_{es} (2015) and ESI (2013) at +0.87 (very strong relationship). This result can be interpreted that the material objects measured have many similarities. The slight enough difference is from the point of view, as well as the difference in time of observation.

Finally, the comparison made with the results of the research (Bogoviz et al., 2019). They measured the ES performance index (ESPI) of 5 nations (including Brazil, Russia, China, and India) in 1990 and 2015. ESPI uses 4 dimensions, each dimension contains three indicators, so there are a total of 12 indicators. The comparison results show r of −0.60 in the year 1990, and +0.2 in the year 2015. It interpreted as an inverse (minus) and weak correlation. This result indicated that the material objects measured have many differences, and also the perspective.

The difference between Q_{es} and ESPI, among others, were the fossil-energy import dependencies indicators. Import dependencies have not quantified explicitly in Q_{es}. The E variable in Q_{es} included import, export, domestic production, stock change; for all types of energy. In other words, ESPI measured some elements of E, while Q_{es} measured all elements of E.

Evaluating Q_{es} comparison results with (1) ESI uses 14 indicators to measure 71 nations: ($+0.6 \leq r \leq +0.8$), (2) ESP uses 15-20 indicators to measure 18 nations ($+0.87 \leq r \leq +0.94$), and (3) ESPI uses 12 indicators to measure 5 nations ($-0.6 \leq r \leq +0.2$); it can be concluded

Table 8: Modified rank: Q_{es} and ESP

Nations	1990		2005	
	Q_{es}	ESP	Q_{es}	ESP
USA	1	2	1	2
Japan	2	1	2	1
Indonesia	3	5	4	3
China	4	3	3	4
India	5	4	5	5

Q_{es}: Our result, ESP: ES performance (Sovacool et al., 2011) result.

Table 9: Modified rank: Q_{es} and ESI

Nations	2005	2008	2013	2015
	Q_{es}	ESI	ESI	Q_{es}
USA	1	1	1	2
Russia	2	3	3	1
Japan	3	2	2	3
Brazil	4	4	4	4
China	5	6	6	5
Indonesia	6	5	5	6
Nigeria	7	7	7	8
Pakistan	8	9	9	9
India	9	10	10	7
Bangladesh	10	8	8	10

Q_{es}: Our result, ESI: ES index (Erahman et al., 2016) that the correlation in the ranking depends on the number of indicators and the number of nations. And of course, it is determined by the point of view in observing the core material of a national ES.

4. FUTURE RESEARCH

The concept of EPME will penetrate to the quantification of the discipline-based perspective (D) of science. Dimensions that have so far been developed: such as 7 dimensions (Ang et al., 2015), or 15 dimensions (Azzuni and Breyer, 2018), which developed until 2018, will be regrouped according to the field of science (D).

Also, given the different factors of national interest (exporters, importers, etc.) will be quantified as a weight value (W). Finally, risk factors (R), will be accommodated in the calculation/aggregation index. Because basically, the word "security" in ES states the conditions that result in responding to various risks. The concept of risk (or threat) in ES already expressed by scholars (Kiriyama and Kajikawa, 2014; Winzer, 2012; Zhiznin et al., 2020), and the response to the risk of supply failure is basically in the keywords: diversity (Yergin, 2006).

Mathematically, the formula for obtaining multidisciplinary macro indicators that have the potential to become universal indicators is stated as follows:

$$U_{Qes} = (R)_{1a} (W)_{ab} (D)_{b1} Q_{es} [Esse] \quad (35)$$

where,
Uqes: universal Q_{es}
$(R)_{1a}$: risk matrix,
$(W)_{ab}$: weight matrix,
$(D)_{b1}$: scientific perspective matrix
Q_{es}: quantity of ES material
Esse: Q_{es} unit.

The matrix determined by the number of scientific perspectives (b) and the number of risk factors (a). If the aggregation method is chosen with the same weight, then all components of the W matrix, are 1. Future research on D, W, and R, requires collaboration across disciplines, institutions, and nations. Formula (35) can be developed for historical evaluation and prognosis.

Table 10: Modified rank: Qes and ESPI

Nations	1990		2015	
	Qes	ESPI	Qes	ESPI
Russia	1	3	1	1
Brazil	2	4	2	4
China	3	1	3	3
India	4	2	4	2

Qes: Our result, ESPI: ES performance index (Bogoviz et al., 2019), result

5. CONCLUSION AND POLICY IMPLICATION

This paper has explained the EPME unification process to obtain Q_{es}. Q_{es} is a macro indicator of national energy security conditions. For macro-level analysis, Q_{es} derived into two compounds: the strength compound (ESs) associated with 'Epm' and the waste compound (ESw) associated with "e_1e_2". Q_{es}, ESs, and ESw have been used to measure the performance of the ten most populous nations in the world from 1990 to 2015.

Based on ESs indicators in 2015, the rankings are the USA, China, Russia, Japan, India, Brazil, Indonesia, Pakistan, Nigeria, and Bangladesh. Since 1990, for 25 years, the USA has continued to rank first. Between 1990 and 2015 China and India had managed to rise in rank, resulting in downgrades in Russia, Japan, and Brazil. While Indonesia, Nigeria, Pakistan, and Bangladesh continue to rank 7th, 8th, 9th, and 10th.

ESs of 9 nations strongly correlated with National Power Indicators (NPI). The only nation with an unstable correlation is Nigeria, indicating ESs macro policy instability for 25 years. After observing the correlation coefficient between ESs and NPI from 1990 to 2015, it concluded that there was a maximum ESs for the USA and Japan. Below that number, ESs strongly correlated with NPI. After passing that number, the correlation is strong but negative. This empirical fact shows the phenomenon of 'saturation'; in the USA, occurred before 2005, in Japan occurred after 2005. This phenomenon raises a hypothesis about the maximum ESs that is typical in developed countries.

ESw rankings in 2015: China, US, India, Russia, Japan, Indonesia, Brazil, Pakistan, Nigeria, and Bangladesh. Thus, Bangladesh is the nation with the least amount of waste disposal. From 1990 to 2015, 3 countries showed a decrease in ESw: Russia, Brazil, and Japan; it shows success in managing energy emissions (energy efficiency) and CO_2 emissions.

2015 Q_{es} Ranking: Russia (1,965 [Esse]), USA (1,529 [Esse]), Japan (827 [Esse]), Brazil (564 [Esse]), China (302 [Esse]), Indonesia (173 [Esse]), India (126 [Esse]), Nigeria (108 [Esse]), Pakistan (88 [Esse]), and Bangladesh (36 [Esse]). From 1990 to 2015, the trend of 8 countries continued to increase, the USA continued to fall, while Japan only fell in 2015. Based on the 2015 Q_{es} value categorization, nations classified into three levels: high (Russia, US, Japan), middle (Brazil, China, Indonesia, India, Nigeria), and low (Pakistan and Bangladesh). Over the past 25 years: China, India, Indonesia, Brazil, Pakistan, and Bangladesh, the value of Q_{es} has more than doubled.

The Q_{es} ranking shows a close correlation with the research conducted by (Sovacool et al., 2011) and (Erahman et al., 2016). It concluded after reviewing the Spearman correlation coefficient were was in the range: + 0.60 to +0.94.

Finally, based on an evaluation of ESs and ESw trends from 1990 to 2015, the following macro energy policy implications are presents for each country:

1. To improve the performance of Q_{es}, China, India, the USA, Indonesia, Pakistan, Nigeria, Japan, and Bangladesh are recommended to increase ESs while maintaining (not increasing) ESw. However, considering the phenomenon of

ESs saturation in the USA and Japan, it is necessary to research in-depth the root cause first.

2. To improve the Q_{es} performance in Russia and Brazil are recommended to reduce ESw while maintaining the value of ESs.
3. Based on the Q_{es} value, the difference measured between rank 1 and 10 has been getting smaller over the past 25 years. It shows that the global ES gap relatively reduced. But in absolute terms, it still contrasts. To reduce the inequality it is recommended to increase cooperation between high-level countries (Russia, US, Japan) and low-level countries (Pakistan, Bangladesh). And also, Nigeria (low middle-level) which has shown energy policy instability in the past.

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