

al Asbahi, Ahmed Abdulwali Mohammed Haidar et al.

Article

Novel approach of Principal Component Analysis method to assess the national energy performance via Energy Trilemma Index

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: al Asbahi, Ahmed Abdulwali Mohammed Haidar et al. (2019) : Novel approach of Principal Component Analysis method to assess the national energy performance via Energy Trilemma Index, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 5, pp. 704-713,
<https://doi.org/10.1016/j.egy.2019.06.009>

This Version is available at:

<https://hdl.handle.net/10419/243623>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by/4.0/>



Research paper

Novel approach of Principal Component Analysis method to assess the national energy performance via Energy Trilemma Index



Ahmed Abdulwali Mohammed Haidar Al Asbahi ^{a,*}, Feng Zhi Gang ^a, Wasim Iqbal ^b,
Qaiser Abass ^c, Muhammad Mohsin ^{d,e}, Robina Iram ^a

^a College of Economics and Management Nanjing University of Aeronautics and Astronautics, Nanjing, China

^b College of economics and management Yanshan University China, China

^c Faculty of Economics, Ghazi University, D.G. Khan, Pakistan

^d School of Business Administration, Shaheed Benazir Bhutto University, Shaheed Benazirabad, 67450, Pakistan

^e School of Finance and Economics, Jiangsu University, Zhenjiang, 212013, China

ARTICLE INFO

Article history:

Received 16 February 2019

Received in revised form 2 June 2019

Accepted 19 June 2019

Available online xxxx

Keywords:

Energy performance

Environmental sustainability

Energy Trilemma Index (ETI)

Principal Component Analysis (PCA)

ABSTRACT

The World Energy Council releases the Energy Trilemma Index (ETI) report annually primarily to assess the energy performance of countries worldwide. Nevertheless, the varying preferences of the dimensions in the ETI between the countries are debatable. The objective of this study is weight allocation therefore this study presents two-fold contribution to comprehensively formulate all possible preferences under the interval assessment outcomes by employing the interval decision matrix followed by the Principal Component Analysis (PCA) to assess the national energy performance of top ten countries for the year 2015. Unlike the conventional methods, the significant advantage of PCA for index construction is that it does not allocate ad-hoc and subjective weights to different indicators. The obtained results were demonstrated by measurement of top ten countries energy performance based on ETI of 2015. Through the development of Energy Development Index, Norway was determined as the highest performing country among the top ten countries. This does not coincide with 2015's ETI which regarded Switzerland as the best performing country. Hence, the ranks are arguable. Further results reveals that there are considerable differences in the values of indicators among all countries. The obtained outcome is expected to aid the policy makers to understand the contribution of different indicators.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

At present, the worldwide the energy demand is expected to increase by one-third between 2015 and 2040 due to population growth, increase in mobility due to urbanization and growth in industrialization (Lee et al., 2018). The International Energy Outlook predicted that the global energy entices an increase in CO₂ emissions by 35.6 billion metric tons in 2020 followed by another 7.6% increase in 2040. The non-OECD countries are anticipated to emit about 29.4 billion metric tons while, OECD countries will emit around 13.8 billion metric tons in 2040 (U.S. Energy Information Administration, 2016). To date, several countries have secured affordable and environmental friendly energy

solution while the remaining are attempting to meet the position of those developed countries. These remaining countries requires a comprehensive and rigorous analysis to understand the energy sustainability index in order to attain it.

In line with the above, the World Energy Council (WEC) annually releases report on the energy performance or energy sustainability index which is also called as the Energy Trilemma Index (ETI) (WEC, 2015). The annual World Energy Trilemma Index (WETI) is prepared with the partnership of Global Risk Centre along with Oliver Wyman global consultancy and Marsh & McLennan Companies. This report presents the assessment of country's capability to equilibrate the trade-offs among three dimensions. The countries are comparatively ranked using ETI with regards to their capacity to the provision of affordable, safe and environmentally sustainable energy infrastructure. This has been done through assessing three contending elements of the index. The definition of the proposed index can be classified as: (i) energy security, "reliable energy infrastructure, the effective

* Corresponding author.

E-mail addresses: Eng.asbahi@hotmail.com (A.A.M.H.A. Asbahi), Zhigengfang@163.com (F.Z. Gang), wasimiqbal01@yahoo.com (W. Iqbal), Qabbas@gudgk.edu.pk (Q. Abass), mumu@nuaa.edu.cn (M. Mohsin), Robinamohsin22@yahoo.com (R. Iram).

and well-managed supply of primary energy (from domestic and external sources) and the ability to participate energy companies to fulfil contemporary energy demands”, (ii) energy equity, “the affordable and accessible supply of primary energy across the population” and (iii) environmental sustainability, “the development of renewable and other low-carbon energy supply to ensure the supply and demand-side energy efficiencies”. Nevertheless, there is a need to quantify and analyse ETI in order to rank the contribution of energy security, energy equity and environmental sustainability.

With regard to the above, typically, only a single existing study has appraised the ETI in measuring the national energy performance till date. [Song et al. \(2017\)](#) employed Stochastic Multicriteria Acceptability Analysis (SMAA-2) to evaluate the national energy performance see [Song et al. \(2017\)](#). The authors firstly formulated the problem in interval decision matrix prior to employing SMAA-2. The top 10 countries from the 2015 ETI was then studied. Based on the comparisons made between the published WEC and the derived SMAA-2, rankings of United Kingdom and Canada were better under SMAA-2 as compared to WEC while it was the otherwise for Norway and Austria. Hence, the authors highlighted that the ranks are controversial and unreliable.

Besides the study above, the rest of the studies in this area did not appraise the ETI. Instead, those studies have focused on energy in general [Cook et al. \(2017\)](#) and [Heffron and McCauley \(2017\)](#). Principal Component Analysis (PCA) which symbolizes two essential methods of removal of estimates for large covariance matrices is observed as a suitable method here by the authors in this study to assess the ETI. A well-known illustration of this technique comprises the Intertemporal Capital Asset Pricing Model (ICAPM) presented by [Merton \(1973\)](#) and Arbitrage Pricing Theory (APT) presented an underlying economic principle for the existence of factor model. PCA has large applications such that [Chamberlain and Arbitrage \(1983\)](#) expanded the APT strict factor model for evaluation. In this factor model, the residual covariance's are not essentially slanting.

The historical development of PCA moves towards in contemporary issues like Connor, and [Lever et al. \(2016\)](#), [Zhang et al. \(2015\)](#) and [Bei and Cheng \(2013\)](#) in which authors recommended statistical methodologies to conclude the number of factors at the same time. [Li et al. \(2016a\)](#) presented the approach to demeanour the statistical presumption on the common factors. However, with the passage of time, the researchers showed that by keeping first numerous components, the measurement of the data could be condensed radically, at the same time little information is sacrificed. The properties of PCA build it as a perfect tool to be used as unique collection method included into the artificial neural network (ANN) to forecast and detect the data for decision making. In the line of this research, the estimators of the covariance matrix foundation on visible factors are presented by [Bhowmik et al. \(2018\)](#) for strict factor model while, [Esmaili and Shokoohi \(2011\)](#) extended it for approximate factor model. A factor model can provide the orientation position for reduction estimation. While the estimator is intended for hidden factor models in the field of PCA. Many studies developed an energy and sustainability index based on various indicators and different approaches. For example, [Radovanović et al. \(2018\)](#) proposed energy security index by using PCA. Energy Development Index (EDI) was developed by International Energy Agency to help policymakers. In another study, [Mohsin et al. \(2018a\)](#) proposed a model to measure economic viability to produce renewable hydrogen energy [Rametsteiner et al. \(2011\)](#) and [Holden \(2013\)](#).

To the knowledge of the authors, no study has employed the combination of interval decision matrix and PCA to assess the effectiveness of ETI. Hence, in this study, the combination of interval decision matrix and PCA would be employed to assess the

national level energy performance of ETI Index. Interval decision matrix and PCA evaluate the performance of energy trilemma by measuring the factors score to know the contribution of each variable. Also, normalized dimension and correlation matrix can be found out to develop indicators by using interval decision matrix and PCA. Unlike conventional methods, the significant advantage of using the PCA for index construction is that, PCA does not allocate ad hoc and subjective weights to different indicators. For the construction of the index, the weights allocation in PCA is the outcomes of multivariate statistical analysis of selected indicators ([Yoon and Klasen, 2018](#)). Index construction in PCA depends on numerous factors which need to be considered together ([Topcu and Payne, 2017](#)). Unlike the methodology adopted by the World Energy Council in their report, as well as the existing studies, this study deals with the problem of weight allocation and aggregation in holistic manners which significantly contribute to the existing literature. The obtained analysis will help the policy and decision makers to understand the contribution of different indicators.

Besides, this study also aims to harmonize PCA to construct estimators for the number of standard factors in ETI and to develop the factors structure to construct meaningful estimators of the covariance matrix in a rising measurement situation without necessitating the set of visible common factors. The analysis would be based on a general approximation factor model which leads towards ranking purpose among 35 indicators and three dimensions such as energy equity, environmental sustainability and energy equity. This study would provide a theoretical imminent with the approximation of factor models regarding the strategy for the approximation of the factors to measure the dimension score and the combination of these dimensions score for generating a meaningful index for the decision maker.

2. Case study and indicators

The 2015's ETI prepared by the World Energy Council (WEC) will be used as the case study here. [Table 1](#) shows the formulation of published ETI by WEC. It includes the score of environmental sustainability, energy equity and energy security as inputs and the ranking score of world energy council as an output [Hunter et al. \(2016\)](#) and [Rempel et al. \(2016\)](#). However, the following is considered: the dimensions score of environmental sustainability, energy equity and energy security in a holistic manner rather than individual indicator as inputs and output. Also, the aggregative dimension for highest best performer among 125 countries of the worlds are considered too. The observation of top ten countries for the year 2015 has been selected for empirical estimation. The selection and addition of individual indicators and sub-indicators in the aggregated efficiency score are directed by a set of practical principles. Below are the three indicators present in ETI. (See [Table 2.](#))

(i) Energy security

The dimension of energy security ascertains the ability to fulfil the current energy supply and the future energy demand ([Tyner and Herath, 2018](#)). It takes into account of both the domestic energy reserves, as well as the dependency on foreign energy imports. This dimension consists of several indicators such as the diversity of primary energy supply, energy consumption with GDP growth, import dependence, diversity of electricity generation, energy storage and preparedness (human factor).

(ii) Energy equity

The dimension of energy equity ascertains the accessibility and affordability of primary energy supply across the population ([Mohsin et al., 2018b](#)). It takes into account the affordability of the primary energy source for providing reasonable

Table 1
System of indicators.

Indicators	Unit
Energy security	
Ratio of total energy production to consumption	Percentage
Diversity of electricity production	Percentage
Distribution losses as a% of production	Percentage
Ratio of total primary energy consumption to GDP	kgoe
Days of oil and oil product stocks	Days
Net fuel imports as a % of GDP	Percentage of GDP
Fuel exports as a % of GDP	Percentage of GDP
Energy equity	
Affordability of retail gasoline	Wages & Prices
Affordability and quality of electricity relative to access	
Environmental sustainability	
Total primary energy intensity	kgoe
CO ₂ intensity	kg per \$ of GDP
Effect of water and air pollution	GHG emissions
CO ₂ g/kWh from electricity production	CO ₂ -eq/kWh

Table 2
Formulation of world energy trilemma index.

Rank	Country	Energy security	Energy equity	Environmental sustainability
1	Country 1	X_{11}	X_{12}	X_{13}
2	Country 2	X_{21}	X_{22}	X_{23}
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
N	Country n	X_{n1}	X_{n2}	X_{n3}

fuel cost and social development. This includes subsidy for energy cost. Nevertheless, the above could adversely contribute towards the environmental sustainability and energy security dimensions (Costa-Campi et al., 2017). The dimension of energy equity consists of the indicators such as the accessibility to electricity, accessibility to clean cooking, quality of electricity supply, quality of energy supply in urban and rural areas, cost of electricity, as well as cost of fuel/gas (gasoline, diesel and natural gas) (Hadian and Madani, 2015; Dale et al., 2013).

(iii) Environmental sustainability

The dimension of environmental sustainability ascertains the attainment of energy efficiency from both the supply and demand perspectives (Cameron et al., 2016), as well as the development of renewable and low-carbon sources as energy supply. This dimension consists of the indicators such as energy intensity, efficiency of power generation and T&D, GHG emission trend, changes in the forest area, CO₂ intensity, CO₂ emission per capita and CO₂ emission from electricity generation. Environmental sustainability (Gillingham et al., 2009), energy security and energy equity has a significant contribution to the development of any sustainability index according to Economics (2016), Pollesch and Dale (2016) and Dočekalová and Kocmanová (2016).

The selection and addition of individual indicators and sub-indicators in the aggregated efficiency score are directed by a set of practical principles. Indicators to be considered for the selection will be from an excellent, reputable sources, with accessible current information. Where such data is missing for any entity (country), then data to be used will be the backdated to a maximum two years that have been well thought-out rather than forecasting of data. Indicators are developed to present an eminence with country condition with the context of aggregated efficiency goals. Each indicator focal point is different characteristics of the subject matter being investigated, except the strengthening is needed to ensure the results. Selection of individual indicators is needed to present data for 95% of countries

Table 3
Energy Trilemma Index for the year 2015.

Rank	Country	Energy security	Energy equity	Environmental sustainability
1	Switzerland	10	05	01
2	Sweden	16	17	09
3	Norway	33	18	06
4	UK	04	30	21
5	Australia	44	09	11
6	Denmark	02	56	12
7	Canada	01	02	71
8	France	41	13	13
9	Finland	23	16	51
10	New Zealand	29	35	47

integrated into the aggregated efficiency score. Only countries with available data containing at least 95% of all individual indicators to drive the aggregated efficiency score has been considered. Data for individual indicators are to be taken for calculation of aggregated efficiency score, from a single, joint and a unique source as much as possible, to ensure the comparability between countries.

3. Problem formulation in interval decision matrix

Table 3 shows the relative score of 2015's ETI for top ten countries consisting the indicators of energy security, environmental sustainability and energy equity. Taken together the energy equity, energy security and environmental sustainability, they comprise a high-performance ETI involving an interweave links between private and public sectors, economic, government regulators, national resources, environmental concerns, social factors and individual behaviours (Anastacio, 2017; Li et al., 2016b). European countries are at top 10 positions, except New Zealand. It strengthens that to reach the top, a country performs well across all dimension and to maintain the energy policies which ensure the balanced trade-off between energy security, environmental sustainability and energy equity.

For this reason, Trilemma efficiency of each economy is apparently calculated via weighted average dimension's sum available in the Trilemma Li et al. (2018) and Song et al. (2017).

$$S_i = \sum_{j=1}^3 y_{ij} w_{ij} \quad \text{where } i, j = 1, 2, 3, \dots, n, \quad (1)$$

Where w_{ij} indicates the weights of dimension j with regards to country i ,

$$\text{and } \sum_{j=1}^3 w_{ij} = 1, \quad w_{ij} \geq 0$$

Three dimensions preferences can be changed to all economies, but each economy indeed prefers most benefits itself. Meanwhile, it is hard to establish the set of weights standard to symbolize the policy maker's mindset towards all indicators. An individual preference neglecting situation the excellent option is, first accept it and normalize it before aggregation to obtained outcomes among all preferences. This study presents all possible preferences can be structured as follows.

$$w_{i3} \leq w_{i2} \leq w_{i1}$$

$$w_{i2} \leq w_{i3} \leq w_{i1}$$

$$w_{i3} \leq w_{i1} \leq w_{i2}$$

$$w_{i1} \leq w_{i3} \leq w_{i2}$$

$$w_{i2} \leq w_{i1} \leq w_{i3}$$

$$w_{i1} \leq w_{i2} \leq w_{i3}$$

Nevertheless, it is hard to attain a cluster of consensuses regarding weights. Manjunath and Gross (2017) developed considerable meaningful metric for GHG emission through subjective, objective and integrated techniques to decide the allocation of weights. Existing literature provides different methods unavoidably presenting an increase in various weighting plan (Zhou et al., 2017; Ngo, 2018). This study originates the intervals via the interval decision matrix to determine the energy Trilemma efficiency of each economy under specific preference the upper (max) and lower (min) boundaries of which are symbolized by the most and least valuable assessment results, respectively. This is then used to measure the factors and eigenvalues to fit PCA to ensure the robustness of results. Without loss of generalization, the possible significant point of Trilemma dimension of each country can be done via the following mathematical notation (Economics, 2014; Pepper et al., 2011).

$$\sum_{j=1}^3 y_{ij} w_{ij}$$

$$\text{S.t } w_{i1} \geq w_{i2} \geq w_{i3} \tag{2}$$

$$\sum_{j=1}^3 w_{ij} = 1, \quad w_{ij} \geq 0$$

Most (max)and least (min) favourable energy performance of countries dimension can be measured as (Mousavi et al., 2017; Zhang et al., 2013).

$$\left\{ y_{ij}, \frac{y_{i1} + y_{i2}}{2}, \frac{y_{i1} + y_{i2} + y_{i3}}{3} \right\}$$

The trade-offs about energy Trilemma among different countries involve certain geographic limitations (Yi et al., 2018) policy-making and potential opportunity to prevail the advantages of each energy dimension situation to ensure its position at the top of the listed countries (Fan et al., 2013). For example, Luxembourg has the top score but ranks 122 in energy security while environmental sustainability rank is 103, it is due to the small geographic area and limited diversity and availability of generation capacity and energy resources (Belaid, 2017).

3.1. Principal component analysis and regression coefficients

A well-known methodology used in this study is the PCA. It is a multivariate numerical tool which transforms the set of uncorrelated variables. These uncorrelated variables are called components to the set of correlated variables. The linear combination of these components is original variables. The fundamental logic behind the PCA is the reduction of dimensions of the data set and transformation of the mutually dependent coordinate to significant and independent coordinates of energy (Matteson and Tsay, 2017). While the ETI_{PCA} consist of the country 'J' = J x_{1j} . . . x_{3j} which are also the set of proposed indicators with corresponding to the country 'k' and ε is the error term (Shi and Guo, 2014).

$$ETI_{PCA} = \beta_1 x_{1j} + \beta_2 x_{2j} + \beta_3 x_{3j} + \varepsilon \tag{3}$$

ETI_{PCA} index consists of two composed orthogonal portion which variation due to error term and the variation proposed components in the index, β₁, β₂ and β₃ are coefficients measurements. Computation of the PC is as follows. The first step is the normalization before aggregation. Therefore normalization of proposed indicators is required and make them positively related through index of ETI_{PCA} with the following approach,

$$X_{ik} = \frac{\min(X_{ik})}{\max(X_k) - \min(X_k)} \tag{4}$$

Moreover, another normalization method has been used to normalize benefit type indicators

$$X_{ik} = \frac{\max(X_i - X_{ik})}{\max(X_i) - \min(X_i)} \tag{5}$$

These adjustments transform the proposed variables on the 1-0 scale. Then the calculation of 3 × 3 correlation matrix A of the all selected normalized indicators because the principal components solely dependent upon the correlation matrix or covariance matrix. Therefore, in this weight's linear combination, the PCA are not characteristically either zeros or ones because weights of each PC come from the covariance matrix eigenvectors (Taskinen et al., 2012). For the variables p, the covariance matrix p × p has a set of p eigenvectors: p {e₁, e₂, . . . e_p} and p eigenvalues – p{λ₁, λ₂, . . . λ_p}.

$$Y_1 = e_{11}X_1 + e_{21}X_2 + \dots + e_{p1}X_p$$

$$Y_2 = e_{12}X_1 + e_{22}X_2 + \dots + e_{p2}X_p$$

$$\dots \dots \dots \dots \dots \dots$$

$$Y_p = e_{1p}X_1 + e_{2p}X_2 + \dots + e_{pp}X_p \tag{6}$$

Each PC generated by the eigenvalues as the linear combination weights, so in this case, the kth eigenvector e_k = (e_{1k}, e_{2k}, . . . , e_{pk}), after that the PC Y₁ are formed by Anon. (2016). Moreover, then we solve it for the determinant mathematical equation, |A – λK| = 0 for λ the solution of this equation provides the three-degree polynomial equation in λ and roots can be consequent. These roots are the eigenvalues after eigenvector A. The decreasing order of scale has been arranged and corresponding to each value of A.

$$A = \begin{bmatrix} x & \dots & x \\ \vdots & \ddots & \vdots \\ & \dots & \end{bmatrix}$$

The matrix equation is solved to drive the eigenvalues of eigenvectors comes from all elected indicators (R – λK) = f_k for λ Where f = [f₁ f₂ . . . f_{3j}] f is an eigenvector corresponding to λ j, having the condition that f * f' = 1. So, we have eleven eigenvectors f₁, f₂, f₃ which keeps up the correspondence to λ₁ > λ₂ > λ₃ This is followed by computing the eleven principal components by normalized indicator's weighting with eigenvectors corresponding to eigenvalues λ₁ > λ₂ > λ₃ with the following methods,

$$P_{1j} = x_j f_1$$

$$\dots \dots$$

$$P_{3j} = x_j f_3$$

x_j = [x_{j1}, x_{j2}, . . . x_{j3}] is a standardized vector indicator for country k. The first principal component shows the maximum variation in the original indicators while the second principal component shows the maximum variance of the remaining indicators (Obadi and Korček, 2017). Maximizing the variances facilitate to make the most of information occupied amongst all selected indicators. The calculation is performed as many as possible for the principal components the number of indicators of the oil supply vulnerability and the total variation among all indicators. All the principal components of energy are jointly orthogonal Su et al. (2016) and Hatefi and Torabi (2018). Therefore, in this case,

$$\lambda_j = \text{var}(P_j)$$

It is significant that λ_j = var(P_j) and thus λ₁ + λ₂ + . . . + λ₃ equal to the total variation in ETI_{PCA}. Therefore, the result λ_j/∑ λ_j is corresponding to the fraction of total variation accounted for by P_j. Finally, the ETI_{PCA} index is calculated as the weighted sum of

Table 4

Computed interval decision matrix exhibiting lower and upper intervals for top 10 countries based on 2015's ETI.

Rank	Country	1	2	3	4	5	6
1	Switzerland	0.79,0.91	0.79,0.91	0.87,0.94	0.91,0.97	0.90,1.00	0.91,1.00
2	Sweden	0.65,0.75	0.65,0.77	0.69,0.75	0.72,0.80	0.75,0.89	0.75,0.89
3	Norway	0.26,0.63	0.26,0.63	0.48,0.70	0.63,0.82	0.59,0.93	0.63,0.93
4	UK	0.71,0.93	0.71,0.93	0.48,0.71	0.48,0.71	0.71,0.82	0.56,0.71
5	Australia	0.00,0.58	0.00,0.58	0.44,0.87	0.58,0.87	0.43,0.86	0.58,0.87
6	Denmark	0.49,0.98	0.61,0.98	0.00,0.61	0.00,0.61	0.61,0.91	0.42,0.84
7	Canada	0.67,1.00	0.50,1.00	0.67,1.00	0.50,1.00	0.00,0.67	0.00,0.67
8	France	0.07,0.56	0.07,0.56	0.43,0.80	0.56,0.81	0.45,0.83	0.56,0.83
9	Finland	0.49,0.61	0.39,0.50	0.51,0.74	0.50,0.74	0.29,0.54	0.29,0.51
10	New Zealand	0.35,0.37	0.35,0.36	0.36,0.39	0.36,0.39	0.35,0.36	0.34,0.37

Table 5

Contribution of variables (%) in terms of factors.

Dimensions	F1(%)	F2(%)
Energy security	52.207	3.905
Energy equity	1.201	83.437
Environmental sustainability	46.593	12.659

eleven principal components wherever the weights are variances of succeeding principal components. So, $\lambda_1 + \lambda_2 + \lambda_3 = 0$ is total variation.

$$ETI_{PCA} = \frac{\lambda_1 P_{1j} + \lambda_2 2P_{2j} + \lambda_3 3P_{3j}}{\lambda_1 + \lambda_2 + \lambda_3} \quad (7)$$

Weighted component's simple arrangement of the energy indicators is used because the weighted sum of the normalized description of these energy indicators enables us in this study to show the relative significance of each energy indicators by determining the ETI_{PCA} index score. This study provides estimation of energy performance via interval decision matrix and then used PCA to measure the contribution of energy trilemma variables for ranking purpose. Interval decision matrix and PCA yields robustness in results so the approximation through interval decision matrix and PCA generate a meaningful index for the decision maker.

4. Results and discussions

The interval decision matrix as shown in Table 4 provides valuable information to rank the top 10 performing countries in 2015's ETI according to the energy performance level. This result originates the intervals to determine the energy trilemma performance at national level to ensure the variables are properly ranked. It presents the relative share and contribution of each dimension in the overall ETI of the 10 selected countries. In order to achieve the dimension's relative contribution in overall ETI via PCA, the coefficients and relationship of all dimensions are included in the ETI. It is necessary to understand these coefficients which are not considered as usual regression coefficients because in this case, the dependent variable is not explicit.

Table 5 presents the factor 1 and factor 2 which provides the contribution of each variable in overall national energy trilemma performance. For factor 1, the energy security comprised of 52.207%, environmental sustainability comprised of 46.593% and energy equity comprised of 1.201%. While for factor 2, energy equity comprised of 83.437%, environmental sustainability comprised of 12.569% and finally energy security comprised of 3.905%. Table 5 presents the mean and standard deviation for the different dimensions based on the data from the case study. The mean is 23.5, 14.5 and 12 for environmental sustainability, energy equity and energy security, respectively. While, the standard deviation is at 20.77, 9.48 and 7.81 for energy sustainability, energy equity

and energy security, respectively. Table 6 provides the normalization of ETI dimensions for aggregation purpose to construct an index for ranking of the entities. Based on it, Norway has the highest energy security at 2.18 while, Denmark has the lowest at -1.41 because Denmark's energy security, energy equity and environmental sustainability enables it at top performing rank and it achieved a balanced score. Denmark's balance score of three dimensions shows its success to provision of affordable, reliable and environmentally-sensitive source of energy. Denmark's shows a low dependency imported fuel, standard transmission and distribution of electricity network. Danish national energy metrics has a lower impact on environment even though emission intensity and energy slightly enhanced but yet the contextual performance is good enough to be top at the list. The energy agreement in March 2012 provides an ambitious initiatives towards 100% renewable energy in 2015 and Denmark huge investment in 2020 ensure it the energy efficient country.

For energy equity, Norway once again is the highest at 1.53 while Switzerland is the lowest at -1.32 . For environmental sustainability however, Finland had the highest value at 2.29 while Switzerland has once again the lowest at -0.99 . Switzerland sustained the position in top ten performing countries while shows a fair and strong performance across the board. Switzerland energy security is slightest strong dimension because it consume about 50% of imported energy. The country energy equity performance is also high additionally Switzerland are trying their best to minimize its impacts on environment by consuming ultra-low emission energy resources and infrastructure.

Table 7 shows the eigenvalues, variability and the cumulative score for each dimension. It is premeditated that the eigenvalues are used to decide which factor from ETI to be extracted into the overall PCA analysis as this signifies the relationship among the dimensions. This is called as the factor loading. For example, the results of factor analysis look at the ETI_{PCA} with three variables of energy security, energy equity and environmental sustainability. The variance in percentage of environmental sustainability, energy equity and energy security is the variability in each factor vary from 0% to 100%. The variability percentage in I1, I2 and I3 are 47.247, 36.228 and 16.525, respectively. The values of variance signify the importance of I1 which is 47.247 while, the cumulative values show the total variation are in the dimension of ETI value. The values of the variance in the dimension of ETI shows that the sufficient variation in the score, while the correlation matrix presented in Table 8 clarifies the general correlation between the three indices. 1 indicates total positive correlation while, -1 is total negative correlation and 0 mean no correlation at all. As shown from Table 8, the energy security is negatively correlated with environmental sustainability.

This shows that the safer a country is regarding energy however, it is more difficult for such country to have a sustainable environment and vice versa. ETA_{PCA} is ETI via using PCA and regression coefficients. A low-carbon energy mix and diversified

Table 6
Mean and standard deviation of energy security, energy equity and environmental sustainability dimensions.

Rank	Country	Energy security	Energy equity	Environmental sustainability
1	Switzerland	10	05	01
2	Sweden	16	17	09
3	Norway	33	18	06
4	UK	04	30	21
5	Australia	44	09	11
6	Denmark	02	56	12
7	Canada	01	02	71
8	France	41	13	13
9	Finland	23	16	51
10	New Zealand	29	35	47
Mean		20.3	20.1	24.2
Std. Dev.		16.09	16.22	23.54

Table 7
Eigenvalues, variability and cumulative scores for each dimension.

Dimensions	I1	I2
Eigenvalues	1417	1087
Variability (%)	47.247	36.228
Cumulative (%)	47.247	83.475

Table 8
Correlation matrix between three indices.

Dimensions	Energy security	Energy equity	Environmental sustainability
Energy security	1		
Energy equity	0.18	1	
Environmental sustainability	-0.413	0.123	1

Table 9
Factor scores for each country.

Country	Energy Security (+) / Environmental Sustainability (-) F1	Energy Equity F2
Denmark	-0.495	-1.012
Switzerland	0.529	-1.556
Sweden	0.469	0.888
Canada	-1.018	-0.867
UK	-0.703	0.05
France	0.717	-0.643
Norway	2.381	1.493
Finland	-2.284	1.501
New Zealand	-0.255	0.769
Austria	0.658	-0.625

E = Energy

sources of energy will help to improve environmental sustainability and energy security and but its positive effects may be muffled by predicted increasing energy consumption by up to 46% by 2060. Worldwide CO₂ intensity had been declining from 0.33 t CO₂/\$ in 2000 to 0.27 t CO₂/US\$ in 2014. However, the upward trend in environmental performance and energy equity improved the clean energy access to sustain the economic growth. Also, in total primary energy, the share of renewable energy consumption has enlarged with a figure of 6.8% in 2005 to 9.7% in 2015. Therefore, the regional profile of countries ETI shows an increasing trend towards diversified energy resources that leads to both energy demand management and energy efficiency continue globally obviously.

Regardless of the obvious problems facing by these countries shows that evolution towards sustainable environment and well balanced renewable energy systems is occurring slowly. While the global energy intensity reduced by 4.2% CO₂ emission decreased by 4.5% and the global electrification rate increased up to 85% due to additional 222 million people gained access to electricity. The results shows that Norway, Sweden and Switzerland outstanding perform across the board while Canada is top with energy security dimension while Switzerland leading towards the strong dimension of environmental sustainability. Globally the European countries are leading in environmental dimension through striving CO₂ emission reduction targets embark. A combination of better energy efficiency, deindustrialization, and the consumption of renewable sources ensure decoupling CO₂ emission and economic growth. On the other hand changing consumer preferences and competitiveness might be a major factor of GHG emission sand economic shrunk in the region.

To present the data in a two-dimensional space, a statistical software was used to reduce the three-dimensional space for the two factors (which are principal components), computed by the PCA based on the method mentioned earlier. Fig. 1 shows the

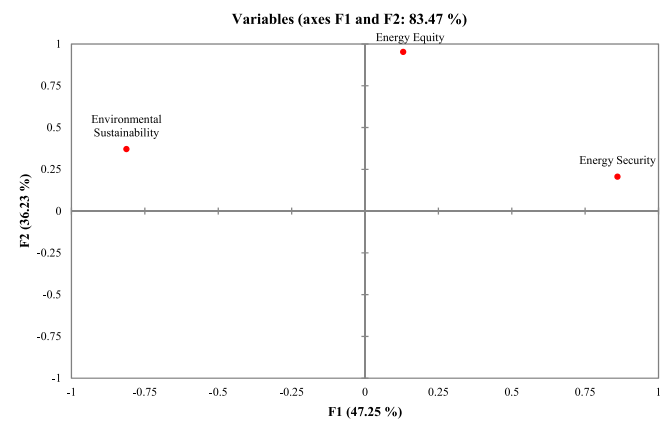


Fig. 1. Contribution of environmental sustainability, energy equity and energy security dimensions.

relative share and contribution of each dimension. The data can be interpreted by using the vertical axis as an accurate measure of Energy Equity (83% accuracy) while, the horizontal axis is an almost 100% accurate illustrator of energy security (and therefore environmental sustainability which is negatively correlated with it).

By using the data from Tables 6 and 8 with normalized values, factor scores for each country were calculated and presented in Table 9. Based on it, Finland for instance ranks high regarding environmental sustainability but is low when it comes to energy security while, the situation is quite the opposite for Norway. Countries such as Austria and France on the one hand, and Denmark on the other, performed relatively equally as can be seen in the table with normalized value.

These countries are also economically stable and they also have the highest capacity to diversify the energy resources. Moreover, the Sweden and Denmark also have high comparatively highest economic resources and less carbon-free resources. Quadrant 2 shows the countries with a below-average energy security and environmental sustainability score and these countries are Finland, and New Zealand. New Zealand is considered as the Pack leader's country in the world in view of the performance of energy security, energy equity and environmental sustainability. Energy security is strong even though New Zealand is a net energy importer country but they produce its 84% electricity within the domestic boundaries. New Zealand electricity production contains diversifying, robust and healthy combination of renewable, hydropower and fossil fuels while the energy security is slightly offset by distribution losses and lower transmission network. New Zealand is well-positioned is also due to improved and continuously increasingly improved macroeconomic position. Lowest heat generation, renewable and hydro power production is lowering CO₂ and other GHG emissions which yielded an improved performance of environmental sustainability.

Those countries mostly rely on conventional energy sources to run their economy mainly to feed the domestic and industrial consumption. They are almost dependent on oil imports with almost equal to zero domestic oil reserves. They also have diversified capacity to focus on renewable energy resources and their energy security is comparatively better to environmental sustainability. On the other hand, quadrant 4 which signifies the reverse situation, as it consists of France, Australia and Switzerland in which these countries are characterized by above-average energy security and environmental sustainability score. They have average industrial energy consumption as compared to other countries in this line. Overall, the best-performing countries on this chart rank near zero on the horizontal axis (indicating a good balance between energy security and environmental sustainability) and high on the vertical axis, indicating high energy equity.

France performance of energy security, energy equity and environmental sustainability make it top performing and it achieved a balanced score of three dimensions though energy security lags to some extent behind as compared to other dimension. Environmental sustainability and energy equity performance is excellent and France produce 10% of its electricity by consuming fossil fuels products. Unlike other countries France has pursue an energetic nuclear policy since the mid-1970s furthermore currently they has the largest power producing capacity through nuclear of any state in Europe while the second only country to the United States in the world.

The results was also employed to plot Fig. 2 which exhibits the countries position in quadrant plane based on the three dimensions. Quadrant 1 shows the best performing situation where Denmark and Switzerland lie in the first quadrant. These countries are economically developed and have a higher share of renewable energy in their total energy mix. Also, they have the highest capacity to diversify their energy sources regarding national interests. Moreover, they have comparatively lowest carbon emission countries in the given set of countries. As can be seen, the Denmark environmental sustainability score is 12 among these countries while Canada has the highest score, which is 72. Canada maintained 7th position in the overall performance but Canada's lower environmental sustainability performance weaken its excellent performance. Energy security and higher energy equity dimension is strong due to major energy exporter tag of Canada. Well diversified electricity production away Canada's from highest emissions even though the dimension of environmental sustainability is weaker than energy security and

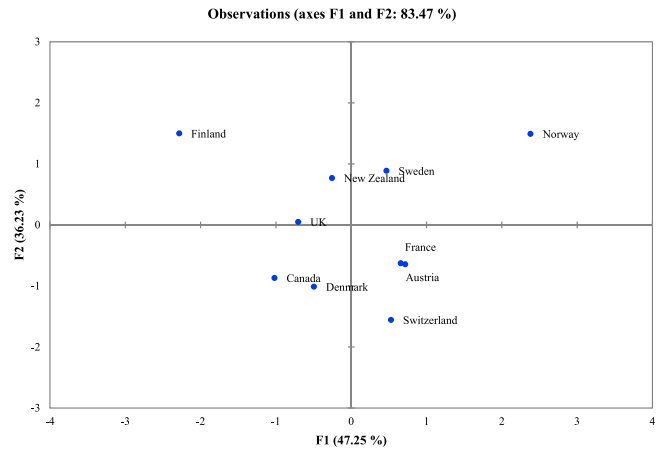


Fig. 2. Position in quadrant based on factor scores.

energy equity. Canada's strong position shows the country's extensive and miscellaneous energy reserve and public and private dedication to expand those energy resources.

Quadrant 3 represents the scenario having the countries which show above-average energy security and environmental sustainability situation. The countries occupy in this quadrant are Norway and Sweden. Like Denmark, Norway and Sweden also have a higher percentage of renewable energy in its national energy mix. Sweden continues his performance fairly well in terms of energy security, energy equity and environmental sustainability dimensions because Sweden also has a well-diversified power production portfolio but energy security score of the country seems bit strong due to better energy production to consumption ratio. Improved energy equity is due to decline in gasoline and electricity prices. The country's major renewable contribution in national power demand considered it the lower emitting, less water and air pollution rank among the best in the world. Surprisingly the Sweden power generation sources contain 98% electricity from low- or zero-carbon while only 2% is being produced from fossil fuel sources. The United Kingdom (UK) facing major problems in energy security unfortunately the fossil fuel domestic production has been declined, the nuclear power plants are going to dilapidated while the coal power projects will be forced to shut down because of European legislation and the agreements in 2015 the Conference of Parties (COP) of the United Nations Framework Convention for Climate Change (UNFCCC) agreed to limit the increase in the global temperature to 2 °C above pre-industrial levels by 2020.

To summarize the above, a combined index called as the energy development index was created. Since the energy equity is observed as the most crucial factor for economic development, it will be assigned 40% of value while, the other two indices were assigned 30%, individually. The ETI that is shown in Table 10 presents the indicators of the development of all dimensions of the environmental sustainability, energy equity and energy security. Among all the countries incorporated in the ETI access to clean cooking and electricity have increased by 74% and 5 to 85%, respectively, since 2000. Meanwhile, clean energy is being used to maintain economic growth and energy access including 9.7% of renewable energy consumption in primary in 2015. Austria continues his performance fairly in energy equity and environmental sustainability dimensions because Austria has a well-diversified power production portfolio but energy security score of the country seems bit weak. It is due to somewhat low oil and oil derivatives stocks, high dependence on imported fuel imports so the energy security does not replicate desired state.

Table 10
Energy development index.

Rank	Country	Energy security	Energy equity	Environmental sustainability	Energy development index
1	Denmark	−1.41	−0.47	−0.84	−0.87
2	Switzerland	0.00	−1.32	−0.99	−0.82
3	Sweden	−0.26	1.32	−0.75	0.23
4	UK	−0.38	−1.21	0.89	−0.33
5	Canada	−0.64	0.05	0.36	−0.06
6	France	0.51	−0.58	−0.60	−0.26
7	Norway	2.18	1.53	−0.94	0.98
8	Finland	−1.15	1.00	2.29	0.74
9	New Zealand	0.13	0.58	0.60	0.45
10	Austria	1.02	−0.90	−0.02	−0.06

The current situation led Austria's towards long term increasing energy security goal and renewable production is more than doubled as compared to 1980 level. Further it is targeted to 34% by 2020 and 100% achieving energy self-sufficiency in 2015.

The results reveal that the contribution of energy security is 28.04, the contribution of energy equity is 42.31 while, the share of environmental sustainability is 29.65 in overall ETI. Three dimensions including energy security, energy equity and environmental sustainability determined the overall situation of a given country. Also, the results show the considerable differences among the dimensions of the selected countries. Finland keep on three dimensions balance score with a slight decline in performance of environmental sustainability. The increasing energy security is due to oil and related products. The dimensions of energy equity shows a strong position due to stable electricity and gasoline prices while the superficial excellence in electricity supply improves through distribution and transmission network. Very interestingly the contextual performance is outstanding, though the economic strength stays lower than the political and societal potency caused by the comparatively elevated living standard cost.

4.1. Sensitivity analysis

PCA is a popular technique in order to analyses data of multivariate structure and it decrease the dismissal of the original data. In order to attain it PCA changes the original series of correlated variables into a set of uncorrelated variables, namely principal components (PCs). The PCs of a data set are evaluated by resolving an eigenvalue problem for the data set covariance matrix. However, in our study we have opted correlation matrix R rather than covariance matrix subsequently the original indicators have different measurement units. In the virtue of PCA model there are supposed n amount of possible solutions which are defined by a set of underlying indicators. The sensitivity analysis performance of energy indicators has been measured through by fixing the eigenvalue λ as 0.5. It is indeterminate that the various value of $v \lambda$ may affect the performance values. Consequently, we considered different λ values and measured the performance score of top 10 performing countries to check what effect varying λ values may have upon the performance scores.

We used nine different values for λ i.e. 0.1, 0.2, ..., 0.9. Table 9 shows the comparative score values of top 10 performing countries. Table 9 shows the values are less sensitive to different values of λ which may indicate that our results are robust generated by proposed method. In essence the first PC (PC1) is associated with the greater value of λ , representing that PC1 defines the biggest portion of the total variance of the proposed problem, followed by second PC (PC2), and so on. (See Table 11.)

5. Conclusion and policy implication

The present study harmonized PCA to construct estimators for the standard factors in ETI and developed the factors structure to construct meaningful estimators of the covariance matrix in an increasing measurement situation without necessitating the set of visible common factors. Analysis based on 35 indicators and three dimensions of ETI were performed. The results revealed that the energy security negatively correlated with environmental sustainability. By further analysing the results through derived factor scores, Finland for instance ranked high regarding environmental sustainability, but low when it comes to energy security. This was then followed by the development of Energy Development Index which demonstrated that Norway has the highest energy performance as compared to the rest of the 9 top countries in 2015's ETI. This does not corroborate with the 2015's ETI which regarded Switzerland as the best performing country. As such, ranks are deemed debatable.

The policy we put forward to meet climate change goals includes:

1. The 21st century energy use should be sustainable and technologies used all sectors including, transport, electricity, heating and cooling should aim to be made affordable, clean and reliable energy. Latest production technologies should be adopted to increase energy efficiency, which in turn will decrease energy intensity.
2. Huge economies like Governments of China, USA and other emerging economies should thus focus their commitments to decrease emissions and save energy under Paris agreement by enacting and implementing energy efficiency policies.
3. Realistic and affordable energy and climate change policy is impossible without an energy efficiency element. Energy security improvement strategies should be adopted to ensure energy efficiency. Energy Management Contracting (EMC) can be adapted to increase energy efficiency.
4. Carbon-free energy sources include wind energy, geothermal energy, solar energy, hydrokinetics, hydropower, and nuclear power should be used to ensure energy security and environmental sustainability. The government should facilitate the public to encourage domestic solar power production and recycle power to national grids. offshore wind power projects should be promoted.
5. There should be an exhaustive focus on planning and policy interaction to encourage latest techniques to reduce waste, such as losses along the energy production, food, distribution and utilization should be researched into and developed.

Table 11
Sensitivity analysis.

Rank	Country	Energy security	Energy equity	Environmental sustainability	Energy development index
1	Denmark	−1.43	−0.45	−0.89	−0.88
2	Switzerland	0.04	−1.29	−0.99	−0.84
3	Sweden	−0.28	1.31	−0.74	0.19
4	UK	−0.41	−1.19	0.81	−0.34
5	Canada	−0.63	0.07	0.38	−0.06
6	France	0.51	−0.59	−0.60	−0.27
7	Norway	2.17	1.53	−0.94	0.98
8	Finland	−1.15	1.11	2.31	0.74
9	New Zealand	0.13	0.58	0.64	0.44
10	Austria	1.00	−0.90	−0.11	−0.09

6. There is a need to control the dramatic increase in demand as well as create consumer awareness towards consumption. Additionally, governments need to reinforce supportive policies regarding non-fossil energy such as removal of tax on the non-fossil fuel and incentivize research and development that promotes carbon-free energy resources.

Limitation of the study is, the policy put forward in this paper is suitable to all countries. But different countries have different performance in three dimensions of ETI, maybe different countries need different policies to improve energy performance. Because it is hard to develop a policy framework for each country and we recommend the extension of this study for future work by proposing the unique policy for each single country.

References

- Anastacio, J.A.R., 2017. *Int. J. Energy Econ. Policy* 7.
- Anon., 2016. Economics I for E, Analysis F. Scholars: 'China has entered the era of post-coal growth'. *Inst. Energy. Econ. Financ. Anal.*
- Bei, L.-T., Cheng, T.-C., 2013. Brand power index – using principal component analysis. *Appl. Econ.* 45, 2954–2960.
- Belaïd, F., 2017. Untangling the complexity of the direct and indirect determinants of the residential energy consumption in France: Quantitative analysis using a structural equation modeling approach. *Energy Policy* 110, 246–256.
- Bhowmik, C., Bhowmik, S., Ray, A., 2018. Social acceptance of green energy determinants using principal component analysis. *Energy*.
- Cameron, C., Pachauri, S., Rao, N.D., McCollum, D., Rogelj, J., Riahi, K., 2016. Policy trade-offs between climate mitigation and clean cook-stove access in south Asia. *Nat. Energy* 1.
- Chamberlain, G., Arbitrage, Rothschild M., 1983. Factor structure and mean-variance analysis on large asset markets. *Econometrica* 51, 1281–1304.
- Cook, D., Saviolidis, N.M., Davídsdóttir, B., Jóhannsdóttir, L., Ólafsson, S., 2017. Measuring countries' environmental sustainability performance—the development of a nation-specific indicator set. *Ecol. Indic.* 74, 463–478.
- Costa-Campi, M.T., del Rio, P., Trujillo-Baute, E., 2017. Trade-offs in energy and environmental policy. *Energy Policy* 104, 415–418.
- Dale, V.H., Efromson, R.A., Kline, K.L., Langholtz, M.H., Leiby, P.N., Oladosu, G.A., et al., 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. *Ecol. Indic.* 26, 87–102.
- Dočekalová, M.P., Kocmanová, A., 2016. A composite indicator for measuring corporate sustainability. *Ecol. Indic.* 61, 612–623.
- Economics, E., 2014. Role of energy efficiency on sustainable development. *Environ. Econ.* 5, 86–99.
- Economics, E., 2016. Ecotourism: a means to safeguard biodiversity and ecosystem functions? *Ecol. Econ.* 29, 303–320.
- Esmaili, a., Shokoohi, Z., 2011. Assessing the effect of oil price on world food prices: Application of principal component analysis. *Energy Policy* 39, 1022–1025.
- Fan, J., Liao, Y., Mincheva, M., 2013. Large covariance estimation by thresholding principal orthogonal complements. *J. R. Stat. Soc. Ser. B Stat. Methodol.* 75, 603–680.
- Gillingham, K., Newell, R.G., Sweeney, J., Brennan, T., Auffhammer, M., Howarth, R., et al., 2009. Energy efficiency economics and policy. *Annu. Rev. Resour. Econ.* 1, 597–620.
- Hadian, S., Madani, K., 2015. A system of systems approach to energy sustainability assessment: Are all renewables really green? *Ecol. Indic.* 52, 194–206.
- Hatefi, S.M., Torabi, S.A., 2018. A slack analysis framework for improving composite indicators with applications to human development and sustainable energy indices. *Econom. Rev.* 37, 247–259.
- Heffron, R.J., McCauley, D., 2017. The concept of energy justice across the disciplines. *Energy Policy* 105, 658–667.
- Holden, M., 2013. Sustainability indicator systems within urban governance: Usability analysis of sustainability indicator systems as boundary objects. *Ecol. Indic.* 32, 89–96.
- Hunter, M., Westgate, M., Barton, P., Calhoun, A., Pierson, J., Tulloch, A., et al., 2016. Two roles for ecological surrogacy: Indicator surrogates and management surrogates. *Ecol. Indic.* 63, 121–125.
- Lee, K.Y., Tsao, S.H., Tzeng, C.W., Lin, H.J., 2018. Influence of the vertical wind and wind direction on the power output of a small vertical-axis wind turbine installed on the rooftop of a building. *Appl. Energy* 209, 383–391.
- Lever, J., Krzywinski, M., Altman, N., 2016. Points of significance: Model selection and overfitting. *Nature Methods* 13, 703–704.
- Li, S., Ma, X., Yang, C., 2018. A combined thermal power plant investment decision-making model based on intelligent fuzzy grey model and its stochastic process and its application. *Energy* 159.
- Li, Y., Shi, X., Yao, L., 2016a. Evaluating energy security of resource-poor economies: A modified principle component analysis approach. *Energy Econ.* 58, 211–221.
- Li, Y., Shi, X., Yao, L., 2016b. Evaluating energy security of resource-poor economies: A modified principle component analysis approach. *Energy Econ.* 58.
- Manjunath, A., Gross, G., 2017. Towards a meaningful metric for the quantification of GHG emissions of electric vehicles (EVs). *Energy Policy* 102, 423–429.
- Matteson, D.S., Tsay, R.S., 2017. Independent component analysis via distance covariance. *J. Am. Stat. Assoc.* 112, 623–637.
- Merton, R.C., 1973. An intertemporal capital asset pricing model an intertemporal capital asset pricing model'. *Source Econom. Econom.* 41, 867–887.
- Mohsin, M., Rasheed, A.K., Saidur, R., 2018a. Economic viability and production capacity of wind generated renewable hydrogen. *Int. J. Hydrog. Energy*.
- Mohsin, M., Zhou, P., Iqbal, N., Shah, S.A.A., 2018b. Assessing oil supply security of south Asia. *Energy* 155, 438–447.
- Mousavi, B., Lopez, N.S.A., Biona, J.B.M., Chiu, A.S.F., Blesl, M., 2017. Driving forces of Iran's CO₂ emissions from energy consumption: An LMDI decomposition approach. *Appl. Energy* 206, 804–814.
- Ngo, D.K.L., 2018. A theory-based living standards index for measuring poverty in developing countries. *J. Dev. Econ.* 130, 190–202.
- Obadi, S.M., Korček, M., 2017. EU energy security-multidimensional analysis of 2005–2014 development. *Int. J. Energy. Econ. Policy* 7, 113–120.
- Pepper, I., Gerba, C., Brusseau, M., 2011. Environmental and Pollution Science. Pollesch, N.L., Dale, V.H., 2016. Normalization in sustainability assessment: Methods and implications. *Ecol. Econ.* 130, 195–208.
- Radovanović, M., Filipović, S., Golušin, V., 2018. Geo-economic approach to energy security measurement – principal component analysis. *Renew. Sustain. Energy Rev.* 82, 1691–1700.
- Rametsteiner, E., Püzl, H., Alkan-Olsson, J., Frederiksen, P., 2011. Sustainability indicator development—science or political negotiation? *Ecol. Indic.* 11, 61–70.
- Rempel, R.S., Naylor, B.J., Elkie, P.C., Baker, J., Churcher, J., Gluck, M.J., 2016. An indicator system to assess ecological integrity of managed forests. *Ecol. Indic.* 60, 860–869.
- Shi, R., Guo, Y., 2014. Modeling covariate effects in group independent component analysis with applications to functional magnetic resonance imaging. *Ann. Appl. Stat.* 1–36.
- Song, L., Fu, Y., Zhou, P., Lai, K.K., 2017. Measuring national energy performance via Energy Trilemma Index: A stochastic multicriteria acceptability analysis. *Energy Econ.* 66, 313–319.
- Su, L., Zhang, J., Wang, C., Zhang, Y., Li, Z., Song, Y., et al., 2016. Identifying main factors of capacity fading in lithium ion cells using orthogonal design of experiments. *Appl. Energy* 163, 201–210.

- Taskinen, S., Koch, I., Oja, H., 2012. Robustifying principal component analysis with spatial sign vectors. *Statist. Probab. Lett.* 82, 765–774.
- Topcu, M., Payne, J.E., 2017. The financial development–energy consumption nexus revisited. *Energy Sources B* 12, 822–830.
- Tyner, W.E., Herath, N., 2018. Energy economics. *Appl. Econ. Perspect. Policy* 40.
- U.S. Energy Information Administration, 2016. *International Energy Outlook 2016*. Vol. 0484(2016).
- WEC, 2015. Energy Trilemma Index. *Energy Trilemma Index*. pp. 1–4.
- Yi, Q., Zhao, Y., Huang, Y., Wei, G., Hao, Y., Feng, J., et al., 2018. Life cycle energy-economic-CO₂ emissions evaluation of biomass/coal, with and without CO₂ capture and storage, in a pulverized fuel combustion power plant in the United Kingdom. *Appl. Energy* 225, 258–272.
- Yoon, J., Klasen, S., 2018. An application of partial least squares to the construction of the social institutions and gender index (SIGI) and the corruption perception index (CPI). *Soc. Indic. Res.* 138, 61–88.
- Zhang, M., Liu, X., Wang, W., Zhou, M., 2013. Decomposition analysis of CO₂ emissions from electricity generation in China. *Energy Policy* 52, 159–165.
- Zhang, D., Shi, X., Sheng, Y., 2015. Comprehensive measurement of energy market integration in East Asia: An application of dynamic principal component analysis. *Energy Econ.* 52, 299–305.
- Zhou, P., Delmas, M.A., Kohli, A., 2017. Constructing meaningful environmental indices: A nonparametric frontier approach. *J. Environ. Econ. Manag.* 85, 21–34.