

Razmjoo, A. Armin; Sumper, Andreas; Davarpanah, Afshin

## Article

# Development of sustainable energy indexes by the utilization of new indicators: A comparative study

Energy Reports

**Provided in Cooperation with:**

Elsevier

*Suggested Citation:* Razmjoo, A. Armin; Sumper, Andreas; Davarpanah, Afshin (2019) : Development of sustainable energy indexes by the utilization of new indicators: A comparative study, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 5, pp. 375-383, <https://doi.org/10.1016/j.egy.2019.03.006>

This Version is available at:

<https://hdl.handle.net/10419/243592>

### 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

## Development of sustainable energy indexes by the utilization of new indicators: A comparative study

A. Armin Razmjoo<sup>a</sup>, Andreas Sumper<sup>a,b</sup>, Afshin Davarpanah<sup>c,\*</sup><sup>a</sup> Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB), Universitat Politècnica de Catalunya (UPC), Av. Diagonal, 647, 08028 Barcelona, Spain<sup>b</sup> Centre d'Innovació, Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB), Universitat Politècnica de Catalunya (UPC), Av. Diagonal, 647, Pl. 2, 08028 Barcelona, Spain<sup>c</sup> Department of Petroleum Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

## ARTICLE INFO

## Article history:

Received 20 January 2019

Received in revised form 12 March 2019

Accepted 19 March 2019

Available online xxxx

## Keywords:

Energy sustainability

Indicators

Sub-indicators

Normalization

## ABSTRACT

Decision making to improve energy sustainability requires scientifically information based on sustainability. Since there are different sustainability targets and specific decision problems in this regard, hence to achieve these targets or solve these problems, relevant sustainability indicators are needed. In this study, is investigated and developed a variety of applicable indicators to enhance sustainable energy development index. Indeed, the main aim of this study is to present new effective indicators related to sustainable development goals, investigating the most important challenges related to energy sustainability. Additionally, this work is following to find the main gaps which are as obstacles in achieving energy sustainability for 12 different countries. To do this, firstly the required data from international energy agency (IEA) and world bank gathered and then is analyzed.

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

## 1. Introduction

Energy importance is not covered on anyone and is a vital need to human, hence the ways of energy providing is also most important (Razmjoo et al., 2017). The affordable and adequate energy supply has a key role in economic development and progress for each country especially in the industrial sector (Razmjoo et al., 2019). On the other hand, energy is a significant factor to achieve sustainable development goals because the use of energy is necessary for economic, environment and social development (Davarpanah, 2018b; Sorrell, 2010). At present the main way of providing energy is fossil fuels but in this sense, two main problems global warming and air pollution that threatens human life and plant and these are creating by fossil fuels. Indeed, the main cause of these problems is CO<sub>2</sub> the issue that creates by fuel fossils (Ebadati et al., 2018; Shirmohammadi et al., 2018). To more prevent of extent this problem, move towards sustainability is useful and effective (Srirangan et al., 2012; Davarpanah and Behnam, 2018). Sustainability is a sophisticated subject and needs for conceptual and analytical discussion and study. The concept of sustainability has means that existing needs can be removed without the need for future generations to meet their needs (Davarpanah et al., 2018; Finkbeiner et al., 2010).

To achieve sustainability moreover specific variety indicators, it also requires regular monitoring of the impacts of selected policies and strategies. One of the most important things related to sustainability is measuring a country's state of development and monitoring its progress or lack of progress towards sustainability. For example, policymakers in each country should have full knowledge of their current state of energy and sustainability in order to help alleviate the problems and develop the country. They must also have a conscious and balanced choice in terms of sustainability indicators so that they can provide development and operation conditions for the country (Moldan et al., 2012). In this regard, it can be mentioned that policy decisions are important to implement effective measurements to achieve sustainable development over time (Hezri and Hasan, 2004). Thus, energy sustainability indicators can be used as a strong tool in the hand of policymakers to assess the level of sustainability of different areas and energy sectors and activities (McCool and Stankey, 2004). Many works in this regard have been conducted. Kemmler A. investigated energy indicators for tracking sustainability. They showed that energy indicators are not only used for environmental and economic issues. Also, it is used and related to social issues (Kemmler and Spreng, 2007). Razmjoo A et al., investigated the role of renewable energy to achieve energy sustainability. They with a study for a city of Iran showed that renewable energy has a remarkable effect for achieving sustainability in energy (Razmjoo and Davarpanah, & Effects, 2019). Assessing rural energy sustainability has been carried out

\* Corresponding author.

E-mail address: [Afshin.Davarpanah@srbiau.ac.ir](mailto:Afshin.Davarpanah@srbiau.ac.ir) (A. Davarpanah).

## Nomenclature

AE	Access to electricity
AREE	Amount of renewable energy in electricity production
CO <sub>2</sub>	CO <sub>2</sub> Emission
EC	Energy conversion
EEX	Energy import
EIM	Energy export
ELC	Electricity consumption
GDP	Gross domestic product
LA	Land Area
LE	Loss of energy
POP	Population
RIFR	Renewable internal freshwater resources
SEDI	Sustainable Energy Development Index
TCO <sub>2</sub>	Total CO <sub>2</sub> Emission
TEP	Total energy production
TEPR	Total energy production from renewable energy
TFCBT	Total final consumption of Biofuel and waste consumption
TFCC	Total final consumption in commercial
TFCET	Total final consumption of electricity in transport
TFCI	Total final consumption in industry
TFCFT	Total final consumption of fossil fuel in transport
TFCR	Total fuel consumption in residential
TFCRC	Total final consumption renewable energy commercial
TFCRR	Total final consumption of renewable energy residential
TFCT	Total final consumption in transport
TFPP	Total final fossil production
TPES	Total primary energy supply
TREP	Total Renewable energy production
Vact	Actual number of indicators
X	Actual number
Xmax	Maximum number of indicators
Xmin	Minimum number of indicators
WAP	Waste and Pollution
x	Array1
y	Array2

by Brijesh M et al., in developing countries. According to this analysis, China has the highest rural energy sustainability index among these countries, and South Africa's has the sixth rank. This shows that one of the most important causes for the progress of South Africa is more access to electrical and renewable energy especially in a rural area (Mainali et al., 2014). Terrapon-Pfaff, J et al. with investigate different project done, shows that one of the ways to reduce poverty in developing countries is more access to sustainable and affordable energy services. They also showed that long-term of small sustainable energy projects in developing countries is an effective and important factor to improve quality of life for inhabitants these countries (Terrapon-Pfaff et al., 2014). An applied quantitative method to evaluating Energy Sustainability Using the Pressure–State–Response as a Case Study in China has been done by S Li et al. They in this study and three main

dimensions of energy, economy, and environment developed a sustainable energy index system including of 20 indicators. They showed to improve the energy sustainability in China's country, should be more effort in these three dimensions (Li and Li, 2019). Saygin, D et al. investigated a benchmarking the energy use of energy-intensive industries in industrialized. They presented a comprehensive overview of the energy use, based on effective benchmark and indicators data with the importance of energy efficiency indicators (Saygin et al., 2011). Kaygusuz, K investigated a study relevant to the energy situation in developing countries to achieve sustainable development, considered in this study. Also in this study, access to electrical energy equally and implementing effective indicators to monitor progress, investigated as important factors to sustainable development. (Kaygusuz, 2012). Few S et al. investigated the energy access via electricity storage to achieve energy sustainability. In this study through different interviews from companies and consumers, the best solutions in order to improve technologies and optimal management of energy presented (Few et al., 2019). A critical review and analysis of energy access programmers for sustainable development, presented by Subhes C. Bhattacharyya. In this paper investigated important energy indicators, on the other hand, emphasized an overall revision related to access energy methods. Also, in this study, suggested to more use of renewable energy as one of the proper ways to access energy (Bhattacharyya, 2012). RFR de Rangel Moreira et al. presented influential indicators relevant to energy sustainable. They in this study, to measure energy sustainability, considered different methods to identify the academic and institutional sources of energy sustainability indicators (de Rangel Moreira and Cândido, 2016). Since sustainable energy development index is leading to achieving completed sustainability, so it needs more investigation. Use of these indicators by policymakers and sustainability experts can be effective to remove the most relevant problems in this regard and lead to more progress. Indeed, when sustainability is complete that all problems have been removed or be minimum. Hence, as much as possible can add more effective indicators to the SEDI, is useful to achieve to complete sustainability. These indicators are effective to progress a country, provided that they become implemented and enhanced properly. Indeed, the indicators of energy sustainability are a set of indicators according to required dimensions of SEDI including different themes and sub-themes and the same conceptual framework. Thus, the main purpose of this paper is to focus on identity and presenting appropriate indicators to measure energy sustainability for different countries. This study has fourth main novelties. First of all, this study investigates all of the weak points of the SEDI method and in order to enhance them, presented a new method by effective indicators that can cover all of the problems. Second of all, this study a new methodology to measure energy sustainability for different countries. Third of all, this study investigates the most influential indicators that have more effect on energy sustainability. Fourth of all, this study trying to find the energy sustainability problems related to 12 studied countries in this research and specify the weak and strong points them by analysis data.

## 2. Importance and relationship of proposed indicators

Indicators are a strong tool to help the policymakers and energy expert to measure energy sustainability which is useful for policymakers, energy analysts and statisticians. Also, indicators give us a deeper understanding of the existing problems (Neves and Leal, 2010). Indeed, energy sustainability indicators, are selected by policymakers or energy experts (Lee and Huang, 2007). They can demonstrate to us, what needs to be done to improve the weak points regarding the current energy system of

a country. Thus, if we can identify and use them correctly, the political targets will be easily achieved (Wu and Wu, 2012). In this research, we present effective indicators related to energy sustainability that are appropriate for implementing in different countries. These presented indicators are to identify the weak points of countries in the line of achieving energy sustainability and can help us to identify the main gaps in energy sustainability policy. Seven selected indicators are the minimum number of an influential group relevant to energy sustainability.

The most important cause for selecting this group of indicators is having a key role in most section of our life. Proper implementation of these indicators can make a high quality of life for all humans in the world. On the other hand, when we improve these indicators, almost the essential problems related to humans will be solved and obtains a high quality of welfare for them. In this section, we describe this group of indicators as below separately.

- The use of fossil fuels is significant for development, but fossil fuels are the main source of carbon dioxide emissions, which is a greenhouse gas and causes environmental pollution and global warming (Davarpanah, 2018a; Ebadati et al., 2019).
- Renewable energy can help human beings to develop and supply energy. Besides, these resources are available and have a positive impact on the environment.
- The importance of transportation as a strategic sector for cities and countries is significant. This section can provide prosperity for residents and play an important role in energy consumption.
- Proper use of energy is most important for preventing significant energy loss. In this regard, it is important to use of new energy-saving technologies.
- Access to affordable and easy energy is essential for all city residents. Providing new technology and creating the right policy can be effective to gain affordable and proper energy.
- Unexpected accidents can be the main cause of the problems and damage to a city and its people. Creating an adequate infrastructure and having the right program is one way to prevent this problem. In this regard, creating an appropriate policy, welfare insurance, and development is vital.
- The government plays an important role in the development of cities and countries. They can plan in all areas necessary for the people. Energy supply, the use of new technology, easy access to energy, etc., is part of the government's task.

### 3. Novel index calculation of SEDI

In this study, have investigated the Energy sustainability indicators for 12 countries. Since to achieve energy sustainability the SEDI method is not complete and has some limitations. Thus it should be improved and completed. Hence, at first, we investigated all of the energy indicators related to seven selected indicators in this research and after that, using correlation analysis chosen proper indicators and then we obtained the strong and weak points of each them. In the final step and according to this analysis, we obtained the weak and strong sections of each country based on existing indicators. Fig. 1 shows a schematic of the energy supply from primary resources (Source: Authors). This figure was designed based on the existing resource which uses by different sections and about seven selected indexes. As can see, resources will be divided into two main parts as total primary energy supply (TPES) and then these resources used in three important sections such as transport, industrial and household used. At the end of this figure, these resource with breakdown impacts on waste and economic. This figure shows that to achieve energy sustainability based on resources, is need to proper planning and effective policy. Indeed, if we can modify the amount

consumption of energy with considerable resources and use of them correctly in a different section, without a doubt will have low problems in the future. As can see in Fig. 1 seven selected indicators were arranged based process.

Table 1 shows the indicators and sub-indicators related to energy based on the design of Fig. 1. These indicators have the most impact on energy sustainability.

Table 2 shows the selected indicators related group of indicators before correlation. As it is clear in this table, there are the most influential indicators related to a group of indicators.

#### 3.1. Main causes of indicators selection

After gathered raw data, by correlation method analysis, were selected the proper indicators from between all of the existing sub-indicators before final analysis. These analyses show us which indicators are appropriate to final analysis and can effective for achieving energy sustainability in studied countries. Also selected indicators to show us which sub-indicators, if become controlled, can be effective to achieve energy sustainability. Table 5 demonstrates the correlation analysis step for all of the existing indicators before the final assessment. Table 3 shows the selected indicators after correlation and normalization step with related used formula.

## 4. Result and discussion

To achieve an acceptable result in this study firstly should be collected the required data for all of the related sub-indicators with the main group of indicators. Therefore, in this regard, the necessary data gathered for each country using IEA and Word bank. Moreover, after these data should be investigated and arranged by breakdown formula. These raw data can help us to acquire the proper final sub-indicators that has a remarkable effect on achieving energy sustainability for these countries. Table 4 shows all of the selected indicators data before normalization. As can see a set of indicators were selected to better and comprehensive analysis for this study. The high number of these indicators allow us to take better making the decision also we can be select effective indicators accurately.

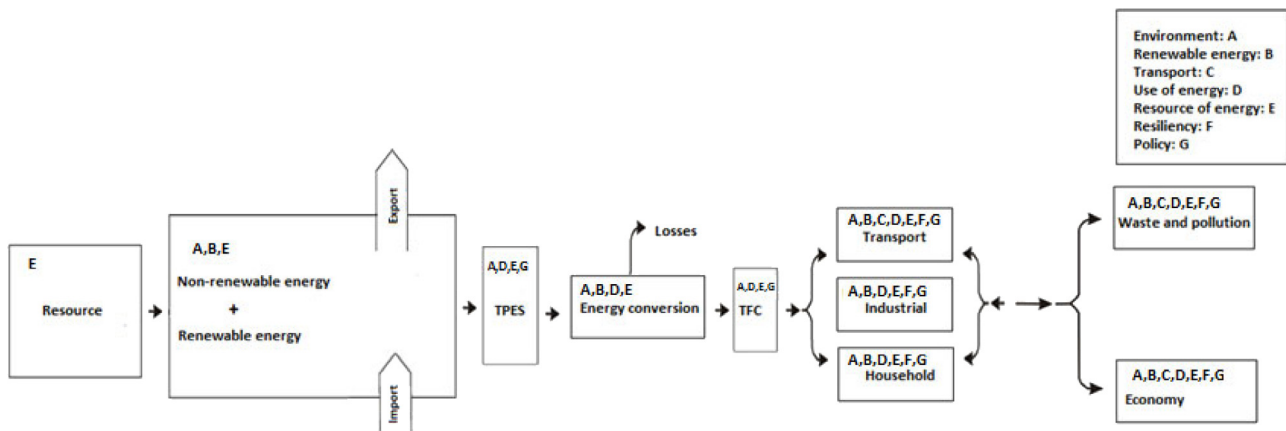
#### 4.1. Importance of correlation and normalization

Correlation and normalization method of obtained numbers is used to achieve better results. Since the main target of this study is achieving energy sustainability, thus it is required that different measure sub-indicators based on related indicators and then obtain main results. In this regard after select, all of the sub-indicators that are related to every seven indicators should be divided all of them into each other before the main correlation step accurately. After that, with the normalization method of the raw data and according to the situation of each main seven indicators, the appropriate sub-indicators will be obtained.

#### 4.2. Correlation and normalization formulation

As before mentioned, the correlation coefficient takes a value between  $-1$  and  $1$  indicating perfect correlation and normalization is a value between  $0$  and  $1$ . Returns the correlation coefficient of the Array1 and Array2 cell ranges that are used to determine the relationship between two properties. Thus the correlation can be obtained as follows a formula that extracted of the excel software:

$$\text{Correl}(X, Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (1)$$



**Fig. 1.** A schematic of energy supply from primary resources.

Source: Authors

**Table 1**

Influential indicators and sub-indicators based on the design of Fig. 1.

Sub-indicators/indicators	Resource	TPES	EC	TFC	Transport	Industrial	Household	WAP	Economy
Total non-renewable and renewable energy	✓	✓	×	×	✓	✓	✓	✓	✓
Total production energy by non-renewable energy	×	✓	×	×	✓	✓	✓	✓	✓
Total production energy by renewable energy	×	✓	×	×	✓	✓	✓	✓	✓
Non-renewable end renewable resource	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total consumption energy by non-renewable energy	×	×	×	✓	✓	✓	✓	✓	✓
Total consumption energy by renewable energy	×	×	×	✓	✓	✓	✓	✓	✓
Amount of CO <sub>2</sub> emission	×	✓	✓	✓	✓	✓	×	✓	✓
Amount of investments in energy	×	✓	×	✓	✓	✓	✓	✓	✓
Reduction fuel fossils by technology	×	×	✓	✓	✓	✓	×	✓	✓
Amount of energy intensity	×	✓	×	✓	✓	✓	✓	✓	✓
Electrical consumption by renewable end non-renewable energy	×	×	×	✓	✓	✓	✓	✓	✓
Percent of economic growth by energy sector	×	✓	✓	×	✓	✓	×	✓	✓
Amount of investment on industrialization and energy	×	✓	×	×	×	✓	×	✓	✓
Amount of energy export and energy import	×	×	×	×	✓	✓	×	×	✓

**Table 2**

Selected indicators related group of indicators before correlation.

Group of indicators	Sub-indicator (Energy)
Environmental impact	Total CO <sub>2</sub> (Mt of CO <sub>2</sub> ), CO <sub>2</sub> /TPES(Mt CO <sub>2</sub> ), CO <sub>2</sub> /population (Mt CO <sub>2</sub> ), CO <sub>2</sub> /GDP (billion 2010 USD -Mt CO <sub>2</sub> )
Renewable energy	Total Energy production from renewable energy/Renewable heat consumption, Amount of renewable energy in electricity production/Total Energy production from renewable energy (Ktoe), TFC Renewable energy consumption in Residential/Total Energy production from renewable energy (Ktoe), TFC Renewable energy consumption in Commercial/Total Energy production from renewable energy (Ktoe)
Transport	Total TFC in transport (Ktoe), TFC of Fuel fossils use in transport/Total TFC in transport (Ktoe), TFC of Electricity in transport/Total TFC in transport (Ktoe), TFC of biofuels and waste consumption/Total TFC in transport (Ktoe)
Use of energy:	Loss/TPES, TFC Residential/population (Ktoe), TFC Industry/population (Ktoe), TFC Commercial/population (Ktoe), TPES/GDP (Ktoe), Electricity consumption/population (Ktoe)
Resource access to energy	Total Energy production (Ktoe), Total fossil fuel production/Total Energy production, Renewable energy production/Total Energy production (Ktoe)
Resilient & safety	Access to electricity (Million population), Renewable internal freshwater resources, per capita (cubic meters), Electricity consumption/population (MWh/capita), CO <sub>2</sub> /population(Mt CO <sub>2</sub> /capita, Population/Land area(sq. km)
Policy	Energy exports/Energy imports (Mtoe), GNI coefficient, GDP (billion 2010 USD)/population

In this formula,  $n$  is  $\bar{x}$  and  $\bar{y}$  are the sample means average (array1) and average (array2).

Also, the main below formula can be used to calculate normalization:

$$X_m = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (2)$$

where in this formula,  $X_m$  is indicator value,  $x$  is the actual number;  $X_{\min}$  is minimum number and  $X_{\max}$  is the maximum number. On the other hand, about difference indicators with various ranges and dimensions, the normalization technique called UNDP method is used to obtain results (Iddrisu and Bhattacharyya,

2015).

$$V = \frac{V_{act} - V_{\min}}{V_{\max} - V_{\min}} \quad (3)$$

$$V = \frac{V_{\max} - V_{act}}{V_{\max} - V_{\min}} \quad (RP40)$$

To arrange the numbers equally, it should be considered that when a definition indicator should have high-value, the Eq. (3) is better to use for normalization and when an indicator should have low value is better than the use of Eq. (4) for normalization. In two formula  $V$  is the indicator value,  $V_{act}$  is the actual indicator



**Table 3**

Selected indicators after correlation and normalization step.

Group of indicators	Sub-indicator formula
Environmental impact	CO <sub>2</sub> /TPES CO <sub>2</sub> /Population CO <sub>2</sub> /GDP
Renewable energy	Amount of renewable energy in electricity production/Total Energy production from renewable energy TFC Renewable energy consumption in Residential/Total Energy production from renewable energy TFC Renewable energy consumption in Commercial/Total Energy production from renewable energy
Transport	TFC of Fuel fossils use in transport/Total TFC in transport TFC of Electricity in transport/Total TFC in transport
Use of energy	Loss/TPES TFC/GDP
Resource access to energy	Total fossil fuel production/Total Energy production Renewable energy production/Total Energy production
Resilient & safety	Access to electricity Renewable internal freshwater resources, per capita Electricity consumption/population
Policy	GNI coefficient

**Table 4**

Raw data selected of Indicators before normalization.

Indicator Country	New Zealand	Austria	Iran	Denmark	Poland	Peru	France	Romania	Turkey	Tunisia	Jordan	Slovakia
CO <sub>2</sub> /POP	6.392	7.241	6.976	5.761	7.716	1.594	4.382	3.441	4.299	2.252	2.499	5.529
CO <sub>2</sub> /GDP	0.17	0.15	1.156	0.094	0.511	0.264	0.104	0.341	0.302	0.51	0.774	0.285
TCO <sub>2</sub>	30	63	563	33	293	51	293	68	339	25	24	30
CO <sub>2</sub> /TPES	1.427	1.891	2.273	1.995	2.95	2.114	1.199	2.142	2.479	2.273	2.674	1.181
TEPR	8720	9770	1940	3490	9030	4700	23900	6100	17130	1180	270	1600
AREE/TEPR	0.356	0.471	0.741	0.433	0.221	0.477	0.359	0.387	0.453	0.042	0.296	0.368
TFCFT/TFCT	0.9981	0.9062	0.9991	0.9346	0.96	0.9578	0.9079	0.9396	0.9922	0.9966	1	0.9215
TFCET/TFCT	0.001	0.0314	0.0008	0.0086	0.0152	0.0005	0.0211	0.0156	0.0037	0.0033	0	0.0212
TFCT	4891	8559	44838	4160	18539	7873	43830	5762	26483	2388	2768	2448
LE/TPES	0.013	0.018	0.012	0.048	0.015	0.019	0.018	0.033	0.022	0.023	0.019	0.02
TFCI/POP	0.00009	0.0009	0.00054	0.00037	0.00038	0.00015	0.0004	0.00003	0.00033	0.00019	0.00011	0.00061
TFCR/POP	0.00003	0.00072	0.00068	0.00077	0.00051	0.00011	0.00059	0.00374	0.00026	0.00018	0.00013	0.00003
TFCC/POP	0.00026	0.0003	0.00014	0.00034	0.00022	0.00003	0.00034	0.000091	0.00015	0.00005	0.00004	0.00024
TPES/GDP	119380.6	79330.9	508546.2	47525.8	173310.6	124984.4	86896.1	159492.4	121852	224469.3	289516.1	157104.7
ELC/POP	8.523	8.275	3.135	5.935	4.187	1.18	7.149	2.682	3.094	1.531	1.874	5.16
TREP/TEP	0.5	0.9	0	0.3	0.1	0.2	0.2	0.2	0.5	0.2	0.8	0.3
TFFP/TEP	0.5	0.1	1	0.7	0.9	0.8	0	0.6	0.5	0.8	0.2	0.1
TEP	16,450.00	12,371.00	391,088.00	15,036.00	66,666.00	25,379.00	131,560.00	24,868.00	36,102.00	6,044.00	355	6,543.00
AE	100	100	100	100	100	94.9	100	100	100	100	100	100
RIFR	72,510.00	6,435.00	1,639.00	1,063.00	1,410.00	52,981.00	3,016.00	2,129.00	2,947.00	376	77	2,325.00
POP/LA	17.8	105.4	49.6	135.5	124	25	122.1	85.9	102.4	71.5	108.2	112.8
EEX /EIM	0.31	0.329	13.323	0.862	0.404	0.985	0.2	0.464	0.064	0.324	0.071	0.348
GNI	0.361	0.305	0.388	0.285	0.321	0.443	0.323	0.275	0.412	0.358	0.337	0.261
GDP /POP	38	48	6	61	15	6	42	10	14	4	3	19

such as a country,  $V_{max}$  is the maximum value of indicator and the  $V_{min}$  is the minimum value of the indicator. Table 5 show the correlation analysis step for all of the existing indicators before the final assessment. In this table correlation method was performed for all arrays and in comparison each other with regard to main its indicator separately. This analysis help us to select appropriate sub-indicators in final step also this analysis shows which sub-indicators are more close to energy sustainability before final selection. Of course, it is possible in this analysis instead of one sub-indicator, two sub-indicators be appropriate for the main indicators, thus each two them can be used in the final selection step.

In this research, the below formula was used to final calculation of each indicator.

$$U = \frac{\sum_{k=i}^n (1 - V_x) + \sum_{y=n+1}^m U_y}{N} \quad (4)$$

In this formula, N is the number of indicators and  $1 - V_x$  is a ratio for the indicators that should be low value. In fact, when a definition indicator should have high-value is not need to use the  $1 - V_x$  for it and it can be calculated without considering  $-1$  for it and when the indicator should have low value is better that the use this equation  $1 - V_x$ . Table 6 demonstrates the obtained numbers of Indicators data after normalization step. Since the range of obtained data for easy analyses, should be identical, thus

**Table 5**

The correlation analysis step for all of the existing indicators before the final assessment.

Indicator	A	B	C	D	E	F
Environmental impact	CO <sub>2</sub> /TPES	CO <sub>2</sub> /Pop	CO <sub>2</sub> /GDP	Total CO <sub>2</sub>		
Column	A–B	A–C	A–D	–		
Correlation number	0.906	0.535	0.239			
	B–C	B–D	–	–		
	0.023	0.393				
	C–D	–				
	0.531					
Renewable energy	TEPR	AREE/TEPR				
	A–B	A–C				
	0.047	0.232				
	B–C	B–D				
	0.191	0.169				
	C–D	–				
	0.968					
Transport	TFCT/TFCT	TFCT/TFCT				
	A–B	A–C				
	0.786	0.009				
	B–C	–				
	0.005	–				
	–					
Use of energy	LE/TPES	TFCT/POP	TFCT/POP	TFCT/POP	TPES/ GDP	ELC/POP
	A–B	A–C	A–D	A–E	A–F	A–G
	0.164	0.427	0.16	0.423	0.055	0.323
	B–C	B–D	B–E	B–F	B–G	–
	0.225	0.559	0.017	0.481	0.157	
	C–D	C–E	C–F	C–G	–	
	0.096	0.031	0.108	0.067		
	D–E	D–F	D–G	–		
	0.488	0.903	0.195			
	E–F	E–G	–			
	0.466	0.0844				
	F–G	–				
	0.221					
Resource of energy	TREP/TEP	TFFP/TEP	TEP			
	A–B	A–C	–			
	0.592	0.513				
	B–C	–				
	0.352					
Resiliency	AE	RIFR	ELC/POP	EC/POP	POP/LA	
	A–B	A–C	A–D	A–E	–	
	0.534	0.371	0.491	0.509		
	B–C	B–D	B–E	–		
	0.243	0.081	0.785			
	C–D	C–E	–			
	0.667	0.161				
	D–E	–				
	0.217					
Policy	EEX/EIM	GNI	GDP/POP			
	A–B	A–C	–			
	0.281	0.242				
	BC	–				
	0.425					

as can see in this table all numbers are arranged in 0 and 1 ranges by Minitab software.

#### 4.3. A comprehensive discussion about obtained results after normalization for sub-indicators

To achieve logical results in this study, all country should be evaluated based on each indicator separately. These stages have two main goals. First of all, it shows the performance of each country based on these indicators and then obtains weak and strong sections of these countries.

- **Environmental impacts:** In this factor, the countries should have has low consumption of CO<sub>2</sub> is better. Because of these indicators emphases on low emission of fossil fuels.
- **Renewable energy:** High consumption of renewable energy has two benefits. Firstly, decreasing the dependence on fossil fuels and secondly low pollution. Therefore, as possible

as using renewable energy should be the priority for each country in energy sustainability plan.

- **Transport:** In this indicator, although fossil fuels are the main resources of energy supply but should be used renewable energy instead of fossil fuels and it can be performed during specified times slowly. Access to more electricity is recommended for this indicator because it will have caused more use of public transport and it leads to low emission CO<sub>2</sub>.
- **Use of Energy:** This indicator is low complicated. It means that if a country can more use of energy, actually it shows that this country is independent in energy import. However, the most important thing in this regard is balance in the kind of energy that uses in a country. Countries should have the correct consumption of energy.
- **Resource access of energy:** More resource for each country is a value, but correct usage them is more valuable.

**Table 6**

Sub-indicators data after normalization.

Indicator Country	New Zealand	Austria	Iran	Denmark	Poland	Peru	France	Romania	Turkey	Tunisia	Jordan	Slovakia
CO <sub>2</sub> /POP	0.783	0.922	0.879	0.681	1	0	0.455	0.301	0.441	0.107	0.147	0.642
CO <sub>2</sub> /GDP	0.072	0.053	1	0	0.392	0.16	0.009	0.233	0.196	0.392	0.64	0.179
CO <sub>2</sub> /TPES	0.139	0.401	0.617	0.46	1	0.527	0.01	0.543	0.734	0.617	0.844	0
AREE/TEPR	0.356	0.471	0.741	0.433	0.221	0.477	0.359	0.387	0.453	0.042	0.296	0.368
TFCRER/TEPR	0.002	0.014	0.001	0.003	0.007	0.004	0.004	0.001	0.108	0.041	0.47	0.003
TFCREC/TEPR	0.006	0.005	0.001	0.001	0.001	0.003	0.001	0.003	0	0.002	0.13	0.001
TFCFT/TFCT	0.998	0.906	0.999	0.934	0.96	0.957	0.907	0.939	0.992	0.996	1	0.921
TFCET /TFCT	0.001	0.031	0.001	0.008	0.015	0.001	0.021	0.015	0.003	0.003	0	0.021
LE/TPES	0.013	0.018	0.012	0.048	0.015	0.019	0.018	0.033	0.022	0.023	0.019	0.02
TFC/GDP	0.104	0.023	1	0.04	0.133	0.152	0.045	0.143	0.026	0.141	0	0.063
TREP/TEP	0.531	0.855	0.004	0.257	0.146	0.185	0.194	0.248	0.486	0.195	0.757	0.275
TFFP/TEP	0.467	0.143	0.991	0.742	0.853	0.814	0.007	0.633	0.513	0.792	0.242	0.115
AE	1	1	1	1	1	0	1	1	1	1	1	1
RIFR	1	0.088	0.022	0.014	0.018	0.73	0.041	0.028	0.039	0.004	0	0.031
ELC/POP	1	0.965	0.24	0.635	0.388	0	0.806	0.176	0.234	0.014	0.062	0.526
GNI	0.361	0.305	0.388	0.285	0.321	0.443	0.323	0.275	0.412	0.358	0.337	0.261
GDP /POP	0.603	0.776	0.052	1	0.207	0.052	0.672	0.121	0.19	0.017	0	0.276

**Table 7**

The obtained number only for selected indicators after normalization stage and using one formula.

Country	Indicator						
	Environmental impact	Renewable energy	Transport	Use of energy	Resource of energy	Resiliency	Policy
New Zealand	0.636	0.121	0.001	0.697	0.532	1	0.621
Austria	0.509	0.163	0.062	0.657	0.856	0.684	0.735
Iran	0.116	0.247	0.001	0.751	0.007	0.421	0.332
Denmark	0.588	0.146	0.044	0.546	0.258	0.55	0.858
Poland	0.163	0.076	0.027	0.509	0.147	0.469	0.443
Peru	0.736	0.161	0.028	0.377	0.186	0.243	0.304
France	0.81	0.121	0.061	0.613	0.594	0.616	0.675
Romania	0.605	0.13	0.04	0.438	0.308	0.401	0.423
Turkey	0.507	0.187	0.005	0.421	0.487	0.425	0.389
Tunisia	0.588	0.028	0.002	0.388	0.202	0.339	0.33
Jordan	0.411	0.299	0	0.358	0.758	0.354	0.332
Slovakia	0.691	0.124	0.052	0.528	0.58	0.519	0.507

A country with appropriate planning also effective policy can use energy resources properly in the line of energy sustainability.

- **Resilient & safety:** Access to electricity, healthy water is more important in this indicator because providing primary requirements is very important for having the welfare of inhabitants.
- **Policy:** This indicator should be attended than other indicators. Because proper policies are one of the most important things to progress and keep up the existing resources, also appropriate policy can lead to achieving energy sustainability.

Table 7 shows the obtained number only for selected indicators after normalization stage. This numbers table including the amount of total energy consumption, amount of fossil fuel consumption, amount of renewable consumption based on resource and policy. As can see in this table, there are two remarkable colors green and red. It means for these countries the strong and weak indicators. The green color represents the desired indicators for the same country and the red color red an undesirable indicator that needs improvement. Since that for easy arrangement of the raw numbers, the normalization should be in range 0 and 1, therefore, the maximum range for this table 1 and the minimum is 0.

Fig. 2 shows the status of each country based obtained numbers of data and indicators. In this figure showed the performance of 12 studied countries based on seven selected indicators. For example, in the resiliency indicators, New Zealand country has a better situation than other countries that are a good situation for this country. On the other hand, and as can see in the use of energy indicators, Iran has a most percent of energy consumption than other countries that this cannot be desirable for this country, as a result, in this policy should be revised as soon as possible.

Fig. 3 shows the chart number of each country based obtained numbers of data and indicators. All obtained numbers belong to main indicators are between 0 and 1 for all countries in this chart that shows the status them based on their existing data and analysis. In this figure, as can see for each indicator specified a range between 0 to 1 that shows the situation of each country from the energy sustainability point of view. This divided range of indicators demonstrates that for these countries and in which indicators should make an essential change for achieving energy sustainability. Also, which indicator need to be strengthened or continue the existing situation of the indicator.

## 5. Conclusion

Importance of energy sustainability is not cover on each person and country. In this regard take correct decisions by energy



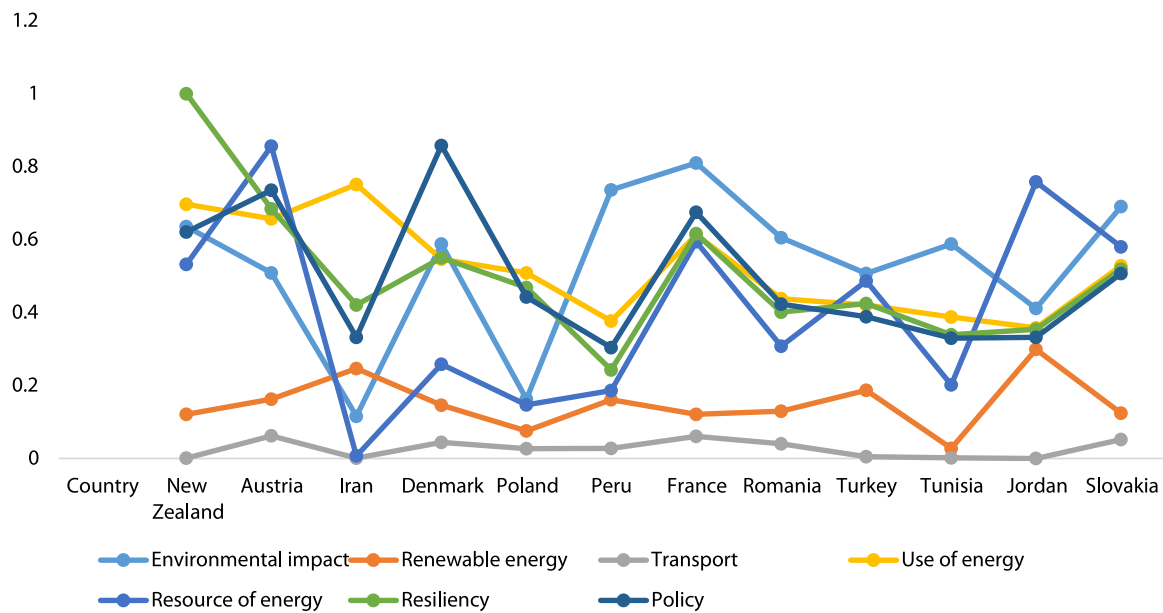


Fig. 2. Status each country based obtained numbers of data and indicators.

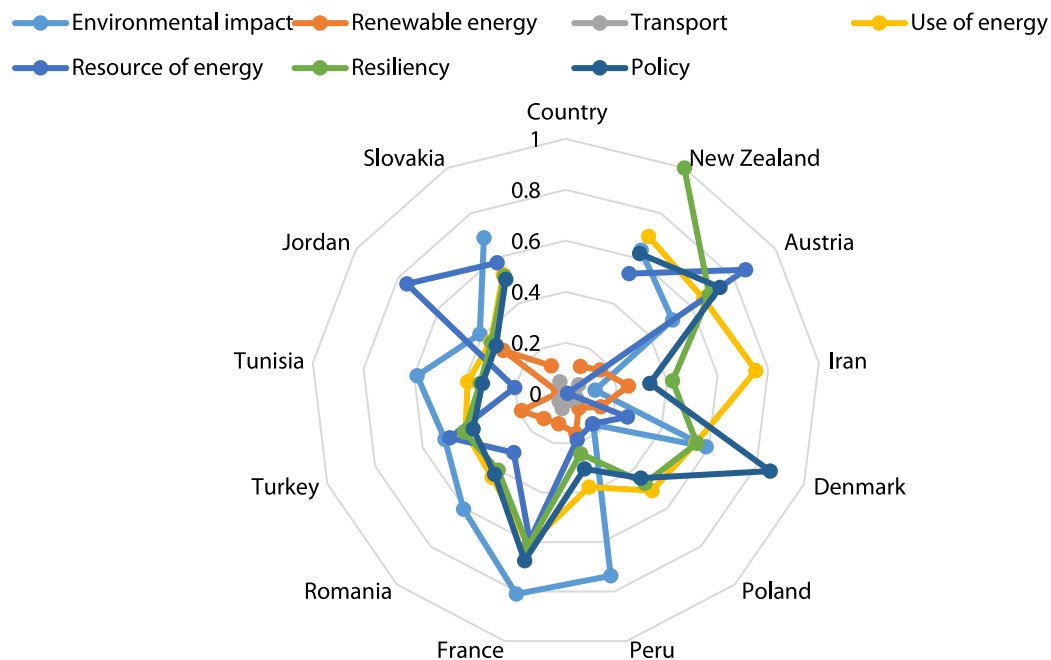


Fig. 3. Chart number of each country based obtained numbers of data and indicators.

makers and energy experts are as a necessity to achieve this goal. Also, the correct determination of energy indicators by them is effective and required to improve and enhance the infrastructure of energy sustainability. In this study, is developed the feasible indicators based on a previously presented method called Sustainable Energy Development Index. This study was presented with new indicators and index to improve energy sustainability for different countries. At first, during a deep study seven indicators in framework, a group were selected, and the related data for each one from the IEA and World Bank cites gathered and analyzed. The conceptual analysis results showed that to achieve energy sustainability is necessary that policymakers and energy experts with regular planning implement the applied policies. Policies such as lower use of fossil fuels over time and substitute them with renewable energy, more attention to public transport,

proper utilization of resources, improving energy infrastructure and resiliency for city inhabitants and rural areas, providing energy access in all area, using new technology to optimize energy consumption and to prevent energy loss. Also, numerical results for 12 studied countries that were presented with two colors green and red has been specified show that which indicators need to enhance and which indicators need to revised and implementing effective actions for it. For instance in the environment section and according to Table 7, the policy of Iran due to more use of fossil fuels as the main resource should be changed and move towards French country that has a desirable situation in this index. Also, for other example and in the transport section, Jordan country should be changed and improved the present its situation and use of effective plans of Australia country to achieve sustainability.

## References

- Bhattacharyya, S.C., 2012. Energy access programmes and sustainable development: a critical review and analysis. *Energy Sustainable Dev.* 16 (3), 260–271.
- Davarpanah, A., 2018a. Feasible analysis of reusing flowback produced water in the operational performances of oil reservoirs. *Environ. Sci. Pollution Res.* 25 (35), 35387–35395. <http://dx.doi.org/10.1007/s11356-018-3506-9>.
- Davarpanah, A., 2018b. A feasible visual investigation for associative foam > \ polymer injectivity performances in the oil recovery enhancement. *Eur. Polym. J.* 105, 405–411. <http://dx.doi.org/10.1016/j.eurpolymj.2018.06.017>.
- Davarpanah, Afshin, Behnam, Mirshekari, 2018. A simulation study to control the oil production rate of oil-rim reservoir under different injectivity scenarios. *Energy Rep.* 4, 664–670.
- Davarpanah, A., Zarei, M., Valizadeh, K., Mirshekari, B., 2018. CFD design and simulation of ethylene dichloride (EDC) thermal cracking reactor. *Energy Sourc. A* 1–15.
- Ebadati, A., Akbari, E., Davarpanah, A., 2018. An experimental study of alternative hot water alternating gas injection in a fractured model. *Energy Explorat. Exploit.* 0144598718815247.
- Ebadati, A., Davarpanah, A., Shahhoseini, A., Ahmadi, P., 2019. An experimental study to measure the required fresh water and treated water for drilling an unconventional shale reservoir. *Int. J. Environ. Sci. Technol.* 1–8.
- Few, S., Schmidt, O., Gambhir, A.J.E.F.S.D., 2019. Energy access through electricity storage: Insights from technology providers and market enablers. 48, 1–10.
- Finkbeiner, M., Schau, E.M., Lehmann, A., Traverso, M., 2010. Towards life cycle sustainability assessment. *Sustainability* 2 (10), 3309–3322.
- Hezri, A.A., Hasan, M.N., 2004. Management framework for sustainable development indicators in the State of Selangor, Malaysia. *Ecol. Indicators* 4 (4), 287–304.
- Iddrisu, I., Bhattacharyya, S.C., 2015. Sustainable energy development index: a multi-dimensional indicator for measuring sustainable energy development. *Renew. Sustain. Energy Rev.* 50, 513–530.
- Kaygusuz, K., 2012. Energy for sustainable development: a case of developing countries. *Renew. Sustain. Energy Rev.* 16 (2), 1116–1126.
- Kemmler, A., Spreng, D., 2007. Energy indicators for tracking sustainability in developing countries. *Energy Policy* 35 (4), 2466–2480.
- Lee, Y.-J., Huang, C.-M., 2007. Sustainability index for taipei. *Environ. Impact Assess. Rev.* 27 (6), 505–521.
- Li, S., Li, R.J.S., 2019. Evaluating Energy Sustainability Using the Pressure-State-Response and Improved Matter-Element Extension Models: Case Study of China. 11(1), 290.
- Mainali, B., Pachauri, S., Rao, N.D., Silveira, S., 2014. Assessing rural energy sustainability in developing countries. *Energy Sustainable Dev.* 19, 15–28.
- McCool, S.F., Stankey, G.H., 2004. Indicators of sustainability: challenges and opportunities at the interface of science and policy. *Environ. Manag.* 33 (3), 294–305.
- Moldan, B., Janoušková, S., Hák, T., 2012. How to understand and measure environmental sustainability: Indicators and targets. *Ecol. Indicators* 17, 4–13.
- Neves, A.R., Leal, V., 2010. Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework. *Renew. Sustain. Energy Rev.* 14 (9), 2723–2735.
- de Rangel Moreira, R.F.R., Cândido, G.A., 2016. Energy sustainability: proposed indicators and their contributions to the adoption of more effective policies and actions for the energy sector. *HOLOS* 8, 3–23.
- Razmjoo, A., Davarpanah, A.J.E.S., Part A: Recovery, Utilization, & Effects, E., 2019. Developing various hybrid energy systems for residential application as an appropriate and reliable way to achieve. *Energy Sustainability* 41 (10), 1180–1193.
- Razmjoo, A., Golipour, M., Shirmohammadi, R., Heibati, S.M., Faraji, I.J.E.p., energy, s., 2017. Techno-economic evaluation of standalone hybrid solar-wind systems for small residential districts in the central desert of Iran. 36(4), 1194–1207.
- Razmjoo, A., Shirmohammadi, R., Davarpanah, A., Pourfayaz, F., Aslani, A.J.E.R., 2019. Stand-alone hybrid energy systems for remote area power generation. 5, 231–241.
- Saygin, D., Worrell, E., Patel, M.K., Gielen, D., 2011. Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. *Energy* 36 (11), 6661–6673.
- Shirmohammadi, R., Soltanieh, M., Romeo, L.M.J.E.P., Energy, S., 2018. Thermoeconomic analysis and optimization of post-combustion CO<sub>2</sub> recovery unit utilizing absorption refrigeration system for a natural-gas-fired power plant. 37(3), 1075–1084.
- Sorrell, S., 2010. Energy, economic growth and environmental sustainability: Five propositions. *Sustainability* 2 (6), 1784–1809.
- Srirangan, K., Akawi, L., Moo-Young, M., Chou, C.P., 2012. Towards sustainable production of clean energy carriers from biomass resources. *Appl. Energy* 100, 172–186.
- Terrapon-Pfaff, J., Dienst, C., König, J., Ortiz, W., 2014. A cross-sectional review: impacts and sustainability of small-scale renewable energy projects in developing countries. *Renew. Sustain. Energy Rev.* 40, 1–10.
- Wu, J., Wu, T., 2012. Sustainability indicators and indices: an overview. In: *HandBook of Sustainability Management*. World Scientific, pp. 65–86.