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Analyzing the relationship between sustainable development indicators and renewable energy consumption

Tarek Abdel-Latif Aboul-Atta[1] and Rania Hamed Rashed[2*]

* Correspondence: raniarashed@gmail.com
[2]Architecture Department, Faculty of Engineering, Cairo University, Cairo, Egypt
Full list of author information is available at the end of the article

Abstract

The transition to renewable energy sources remains a major challenge for developed and developing countries. Therefore, the study aims at investigating the relationship between sustainable development indicators and renewable energy consumption utilizing integrated data sets for 255 indicators expressing the sustainable development goals from 137 developed and developing countries. Principal component analysis then multiple linear regression tests are employed to conclude a mathematical model representing the numerical relationship between a set of sustainable development indicators and renewable energy consumption. The statistical analysis results include (i) an inverse correlation between Sustainable Development Index which expresses the dominant factor representing collected data and renewable energy consumption, (ii) a set of sustainable development indicators as the determinants of renewable energy consumption. The findings explain the rapid transformation of low Sustainable Development Index countries towards renewable energy technology by realizing the effective role of using renewable energy as a local solution. Moreover, the findings manifest the importance of the given sustainable development indicators in obtaining a more significant increase in renewable energy consumption. Using the concluded mathematical mode, planners and decision-makers can compromise the concluded indicators to attain a serious progressing step towards renewable energy transition aligned with achieving sustainable development.

Keywords: Renewable energy consumption, Sustainable Development Goals, Sustainable Development Indicators, Sustainable development Index

Introduction

Energy has a positive impact on health, education, transportation, business, and most crucial; how long people may survive [1]. There is an exponential growing energy demand to meet the global population growth and maintain higher living standards [2]. Primary energy sources are categorized based on long-term availability as renewable and conventional energy resources; thus, consuming energy resources have two critical options, using easily accessed, conventional but unhealthy environmental energy resources or adopting technology-oriented, non-conventional, and healthy environmental energy resources [3]. Nowadays, the world is heavily dependent on depletable energy sources tracking not sustainable pathways. Renewables are responsible for only 20% of global energy consumption, which is a small share compared to its benefits Fig. 1 [4, 5]. Therefore, the transition to renewable energy sources remains a major challenge for developed and developing countries. Renewables are a perfect key for increasing energy security since they are physically available, economically affordable, socially accessible, and publicly acceptable [6]. Geographic limitations are the main obstacle of renewable power technologies. Renewable-based energy generation is still not as cost-effective compared to other energy generation options; it has high initial costs besides the high cost of storing systems although the costs of renewables have been going down [7]. Also, land areas that are required for the installation of energy technology are large compared to plants powered by fossil fuel [8]. Despite some existing limitations and challenges that need to be overcome, clean sources make a significant contribution in providing energy within buildings, industry, and transport sectors. Accordingly, there is an imperative need for exploring the relationship between renewable energy use and sustainable development (SD) to ensure energy access, promote a healthier environment and achieve energy access equality among people.

Importance of renewable energy and sustainable development nexus

United Nations' Sustainable Development Goals (SDGs) are a blueprint that guides societies for achieving progress in all pressing challenges. The United Nations defined the SDGs as "a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity" [9]. Renewable energy expressed in Goal 7 "Ensure access to affordable, reliable, and modern energy for all" is considered the heart of SDGs [10]. Securing access to energy supply is a highly demanding concern, but it is more challenging to provide energy in a sustainable form. Governments worldwide have declared the 17 SDGs to be 'integrated and indivisible' [11]; meaning that SDG7 cannot be achieved in sectoral isolation apart from the achievement of SDGs. Renewable energy is strongly connected to all human activities, and it contributes to achieving urban and environmental sustainability [12]. Ensuring access to renewable energy

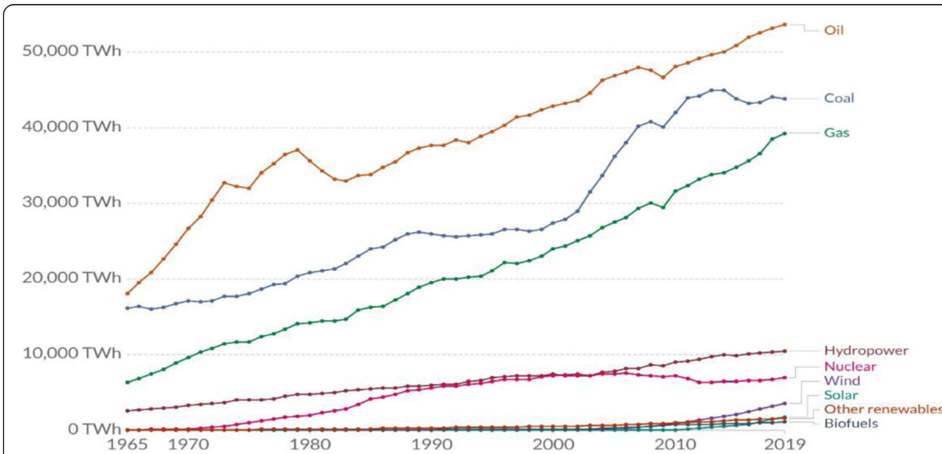

Fig. 1 (Global energy consumption growth by source 1965-2019 - [4, 5]

sources contributes to the implementation of SDGs through enabling development processes and promoting progress path.

The analysis of the relationship between renewable energy and SDGs, which is the main aim of the current study, represents a step for mapping the links between energy systems and social well-being, economic activities, and the environment. Also, this interaction would affect future energy scenarios at national and local levels. The analysis of the relationship between renewable energy and SDGs at the targets level reveals a complex interaction including synergies and trade-offs [13] in which positive interactions between renewable energy and SDGs exceed the negative ones [14]. Evidence of synergies between 143 SDGs targets to achieve SDG7 is established, meaning that about 85% of SDGs targets support SDG7 [15].

The role of renewable energy in achieving Sustainable Development Goals

This section discovers the connection between adopting renewable energy sources and the achievement of SDGs at goals level, using an analysis extracted from three studies, issued from global organizations scoped in SDGs interactions (1) accelerating the global energy transformation [16], (2) mapping the Renewable Energy Sector to the Sustainable Development Goals: An Atlas [17], and (3) a guide to SDG interactions: from science to implementation [18]. Following the results of the reviewed studies, a multi-perspective analyzed summary of the connection between renewable energy and SDGs is listed in Table 1.

Literature review

The focus of the literature search was on the studies that examine the relationship between the use of renewable energy and one or more SD dimensions. The literature section is divided according to the examined SD dimensions, while environmental and economic dimensions have been most discussed among the majority of previous studies.

Renewable energy and environmental dimension

Most researchers use the amount of carbon dioxide (CO_2) emissions to express global climate change and environmental quality. Empirical results, from a series of studies, indicate that CO_2 emissions and REC are inversely correlated and there is a bidirectional causality running from CO2 to REC in developed and developing countries [19–22]. Evidence, from 50 African countries across regions and income levels, confirm that REC contributes to mitigating CO2 emissions within ten years [23]. The result of examining a group of EU countries prove that the use of renewable energy options is a key solution to improve air quality by decreasing greenhouse gas emissions (GHG), where CO_2 is the major component of GHG emissions [24]. A recent study confirms the role of REC in improving environmental sustainability characterizing environmental quality by ecological footprint [25]. Another study finds that global REC has a long-run significant positive impact on environmental sustainability by testing a global framework of developed and developing countries. The study recommends that the roles of renewable energy in increasing environmental quality should be considered by reforming the energy policies to encourage the use of renewable energy sources [26]. The empirical outcomes of a study analyzing the environmental degradation in Japan

Table 1 Multi-perspective summary of renewable energy-SDGs nexus

SDGs	Renewable energy contribution in achievement SDGs
1. No poverty	Renewable electricity generation becomes cost-effective in most regions. Decentralized renewable energy contributes to ending poverty by supporting local economic development, enabling savings on fuel spending and improving the poorest standard of living.
2. Zero hunger	Renewable-powered pumping technologies in remote areas can increase agricultural productivity and improve yields which help in achieving food security and improve nutrition by providing energy for food storage and preservation.
3. Good health and well-being	Depending on renewable sources reduce air pollution which contributes to health improvements and reduce diseases risk. Off-grid renewable systems can secure power supply for remote healthcare and hospitals.
4. Quality education	Renewable energy improves the learning environment by powering schools and homes, allowing study time after nightfall and freeing up time previously required for fuel collection.
5. Gender equality	Access to renewable energy sources allows women effective participation in the work community, as it gives them a source of income by saving fuel collection time. Renewable public outdoor lighting makes the street safer for women to continue activities after dark.
6. Clean water and sanitation	Renewable-based technologies consume up to 200 times less water than other traditional power plants. A shift toward renewable energy can increase clean water supply through desalination power plants grid-connected projects, or off-grid groundwater pumping.
7. Affordable and clean energy	Renewable energy sources support the expansion of electricity access especially in remote areas where it is expensive to connect to centralized grids. Renewables are planned to replace fossil fuels in the global energy mix to hold warming to 1.5 °C.
8. Decent work and economic growth	Deploying renewable technologies and higher energy prices can increase demand for a skilled workforce. The significant growth of renewable energy and potentially displacing fossil fuel employment could increase global GDP and create economic growth.
9. Industry, innovation, and infrastructure	As the costs of renewable technologies continue to drop, the creation of renewables local markets will emerge new local businesses and industries. Supporting renewable-based shifting to make it more reliable and sustainable is a necessary process.
10. Reduced inequality	Relying on local energy sources can encourage socio-economic development and support reducing inequalities between countries. Availability of sources of local renewable energy help in reducing inequalities due to political pressures of fossil fuel market variations.
11. Sustainable cities and communities	Depending on renewable energy in buildings (heating, cooling, and cooking) as well as for transport, will be an essential part of the future's cities. Globally, over 100 cities get more than 70% of their power needs from renewables.
12. Responsible consumption and production	Renewable resources improve resource efficiencies, reduce pollution and increase recycling making the energy supply cleaner and safer. The modularity and locality of renewable energy increase generation efficiency by locating it closer to consumption.
13. Climate action	Displacing fossil fuels in the global energy supply with renewables is linked to keeping the rise of temperatures within 2° above pre-industrial levels.
14. Life below water	Upscaling renewables reduce underwater pipelines, aquatic transport, and fossil fuel tanker traffic. By using renewable energy, CO2 emissions are reduced. Consequently, the reduction of future ocean harm is achieved.
15. Life on land	Providing the world's poor with renewable energy sources will manage land responsibly and preserve ecosystems by decreasing halting deforestation as an energy source. The renewable energy projects can displace the use the charcoal fuel and decrease forest degradation also.
16. Peace and justice strong institutions	Within societies and between countries, it is possible to decrease social and economic inequalities and achieve peaceful and inclusive societies by ensuring renewable energy supply to those who are persistent in need.
17. Partnerships to achieve the goal	Enabling local and global frameworks of partnerships is required to connect renewable energy deployment with SDGs through collaboration with governments, utilities, and grid operators to displace fossil fuels.

demonstrate proof for the existence of an interaction between renewable energy use and CO2 emissions. Hence, in the short and medium terms, renewable energy usage mitigates CO2. The study recommends that Japan should support renewable energy development [27]. Moreover, there is one-way causality from renewable energy consumption (REC) to CO2 emissions in Argentina; thus, renewables improves the environment [28]. Modelling the dynamic linkage between REC and environmental degradation, renewable energy use can predict CO2 emissions in South Korea [29]. A weak negative relationship is shown between renewable energy and CO2 emissions in China, the world's biggest carbon emitter [30].

Renewable energy and economic dimension

A bidirectional causality is running between per capita Growth Domestic Product (GDP) and REC, addressing that developed countries are consuming more renewables sources, while lower GDP countries rely more on non-renewables sources [31, 32]. In most European countries, there is a positive relationship between REC and economic growth; REC has a positive impact on GDP [33, 34]. A panel of data for 102 countries with different income levels were analyzed and the results prove that for low-income countries, REC has a positive relationship with 'industrial and service values added' the industry/service contribution to overall GDP [35]. Testing data, from some Latin American countries, confirm that GDP per capita, technological innovation and trade have a statistically significant positive association with renewable energy use [36]. Evidence, from the association of southeast Asian nations countries, finds that the adopting of renewable sources in energy generation spurs economic growth and creates better export opportunities [37]. There is a positive nexus at the regional level in seven East African countries between the growth of renewable energy and economic growth [38]. In Rwanda, a low-income country, an asymmetric causality relationship running from REC positive shocks to economic growth is noted [39]. Contrary to popular belief, there is a bi-directional relationship between economic growth and the use of renewable energy in developing countries that are rapidly endorsing renewable energy to power the economic growth engine [40].

Renewable energy and other dimensions

A closer look at previous studies shows an average number of researches linking REC to a group of indicators that have not been frequently examined. In developed countries, income inequality is associated with REC, thus increasing REC plays a notable role in reducing income inequality [41]. An increase in the usage of renewable energy leads to a decrease in public health expenditure for the association of Southeast Asian nations countries [37]. Corruption control is positively linked to renewable energy participation; it increases the REC in developed and developing countries [42]. The education level has a significant impact on renewable energy deployment in developed and developing countries [43]. A study has agreed to use 'adjusted net savings' as a good SD variable and the results have confirmed that renewable energy has a statistically significant positive impact on SD for developed and developing countries [44]. Measuring the connection between the Human Development Index (HDI) and renewable energy, a study indicates that the deployment of renewable energy contributes to improving the SD level in 28 OECD countries [45].

The analysis of the above literature has revealed that existing studies have connected REC to limited SDGs dimensions which do not meet the SDGs wide-ranging concept. Previous researches offer an improved understanding of the REC-SDGs nexus. Therefore, the current study addresses the literature gap by examining the relationship between REC and an integrated panel of SDGs indicators.

Methods

The study aims at investigating the relationship between SD indicators and REC by concluding a mathematical model to represent the numerical relationship utilizing data of 255 SDGs indicators from 137 countries. Moreover, the study seeks to find out how effective is a high SD level in increasing REC by testing the adopted hypothesis which proposes that REC is associated with a group of SD indicators and its value can be calculated in terms of these indicators. This quantitative study is based on deductive and statistical analytical approaches to test the adopted hypothesis. The deductive approach extracts a key summary of the relation between renewable energy and SDGs through surfing theoretical background readings and previous studies guidelines. The statistical approach examines the influence of SD indicators on REC, and Fig. 2. illustrates research methodology scheme.

Statistical indicators provide an accurate conception for analyzing and comparing data; therefore, it was crucial to interpret the nexus between renewable energy dependency and SDGs into measurable indicators. Renewable energy is frequently measured by: consumption, production, capacity, and energy supply. The current study agrees to measure the country dependency on renewable energy by consumption which specifies the actual energy need [46]. The arrangement of the SDGs is used as a format for collecting and allocating indicators that are gathered under each associated SDG. The research methods are designed within two parameters: (1) collecting and organizing data, and then (2) applying the statistical model.

Empirical study

Data collecting and organizing

Data source The study depends on three sources of data: (1) SDGs indicators by World Bank [47], (2) Human Development Indices and Indicators by the United Nations Development Program [48, 49], and (3) SDGs indicators from the United Nations

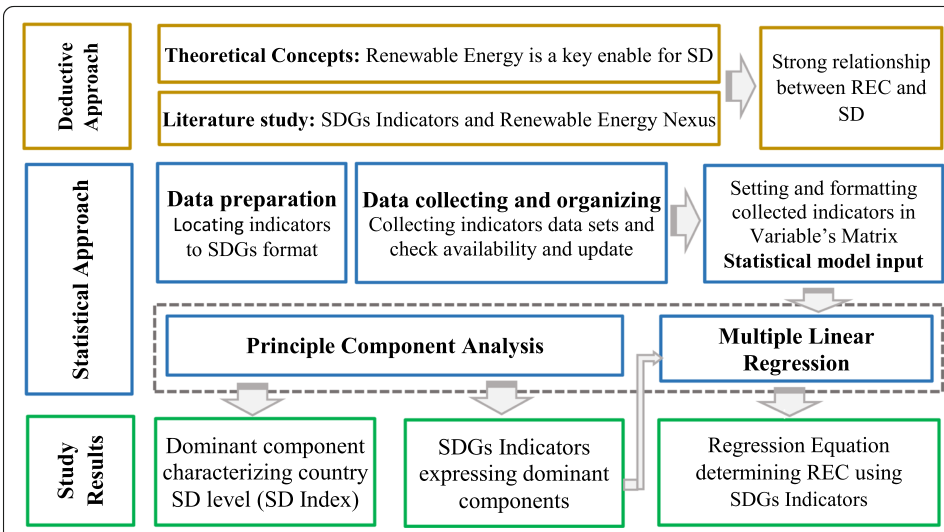

Fig. 2 Research Methodology Scheme

SDGs index and dashboards [50]. Each source endorses a group of indicators for measuring the achievement of SDGs and generates regularly updated data. The study collects each source of the endorsed indicators and compiles them into a preliminary list containing 517 indicators for 218 countries following the World Bank countries list order.

Data availability and update Data within the years 2017, 2018, and 2019 are collected, and 2017 data is selected as it has the most available data. Indicators (variables) and countries are specified within the framework of data availability. An optimization process is applied to filter the collected data, including indicators and countries with complete data or less than 5% missing data, and other indicators are excluded.

Data adjusting Due to the unavailability of some indicators, the study proposes a collection of supplementary indicators to represent demographic aspects, human development, and SDGs' overall performance. The Series Mean method is employed to fill missing data [51] using Statistical Package for Social Sciences (SPSS) software. The matrix variables are is formed from using the adjusted indicators list which compiles 255 SDGs indicators for 137 countries. Figure 3 illustrates the data collection and organizing sequence, and Table 2 indicates additional indicators and variables distribution according to SDGs.

The study divided the statistical model into two tests: (1) principal component analysis (PCA) which is a method used for multivariate data analysis to reduce dimensionality [52]. PCA is a prerequisite for (2) multiple linear regression (MLR) analysis which is a conceptually analytic technique for understanding the interrelationships among variables [53]. Both PCA and MLR analyses are processed by the SPSS software.

Principal component analysis (PCA)

PCA is a widely used method for factor reduction. It reduces dataset dimensionality and preserves as much 'variability' as possible [54]. It applies to large data sets to minimize a large number of variables (indicators) into a small group of components. The study employs the PCA test to compute the dominant components that have the most variances in variables [55]. PCA test is applied by utilizing SPSS software to the 255 collected variables. A preliminary PCA run generates 40 components. The first component accounted for 34.2% of the variance of the variables explained. PCA

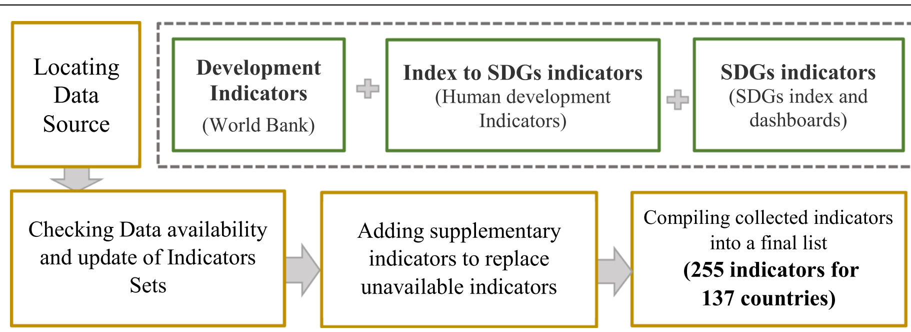

Fig. 3 Data collecting and organizing scheme)

Table 2 Variables distribution according to SDGs indicators and Additional indicators

SDGs	Variables	SDGs	Variables
Demographic indicators	X_1–X_{16}	Goal 10	X_{173}–X_{186}
HD and SDGs overall indicators	X_{17}–X_{21}	Goal 11	X_{187}–X_{196}
Goal 1	X_{22}–X_{28}	Goal 12	X_{197}–X_{205}
Goal 2	X_{29}–X_{35}	Goal 13	X_{206}–X_{211}
Goal 3	X_{36}–X_{64}	Goal 14	X_{212}–X_{213}
Goal 4	X_{65}–X_{82}	Goal 15	X_{214}–X_{222}
Goal 5	X_{83}–X_{91}	Goal 16	X_{223}–X_{232}
Goal 6	X_{92}–X_{101}	Goal 17	X_{233}–X_{255}
Goal 7	X_{102}–X_{111}		
Goal 8	X_{112}–X_{163}		
Goal 9	X_{164}–X_{172}		

analysis is based on which variables are most correlated with each component. Variables correlated with the first component with a saturation value of more than 0.5 whether positive or negative are obtained, while the rest variables are dropped.

To exclude the least influencing indicators a second PCA run is executed on obtained variables. Its results show that the first component of the 14 extracted components accounted for about 61.7% of variables variance which is a high eigenvalue as shown in Table 3. Therefore, the first component has the dominant forces to describe the change that occurred in variables. Variables expressed by the first component can explain 61.7% of a country's SD level. One hundred twenty-six variables obtained from PCA are the input dependent variables in the next statistical analysis phase.

Multiple linear regression analysis (MLR)

MLR is a quantitative analytical tool to explain the behavior of some variables by another variable. The regression equation, which is the result of MLR, has the form of a mathematical function that quantifies the relationships between a set of independent variables and the dependent variable [56, 57]. The regression equation is used to estimate past values and predict future values of the dependent variable in terms of independent variables' values [58]. MLR produces a regression equation that has the form of Eq. (1)

$$\mathrm{Y} = \mathrm{a} + \mathrm{b}_1\mathrm{X}_1 + \mathrm{b}_2\mathrm{X}_2 + \mathrm{b}_3\mathrm{X}_3 + \ldots\ldots + \mathrm{b}_n\mathrm{X}_n \quad (1)$$

Where Y is the response (dependent variable), X_i $(i=1,2, 3\ldots n)$ is the set of predictors (independent variables), bi $(i=1,2, 3\ldots n)$ is the line slope and a is the y-intercept. MLR

Table 3 Part of the first and second runs components of PCA

1st PCA run components	Initial Eigenvalues			2nd PCA run components	Initial Eigenvalues		
	Total	Variance	Cumulative		Total	Variance	Cumulative
1	87.298	34.234	34.234	**1**	77.782	61.732	61.732
2	18.337	7.191	41.426	**2**	8.502	6.748	68.479
3	15.311	6.004	47.430	**3**	3.776	2.997	71.476
4	11.387	4.466	51.896	**4**	3.669	2.912	74.388
5	8.425	3.304	55.199	**5**	3.159	2.507	76.895

analysis is applied within the 126 variables obtained from the first component produced from the PCA second run. The study employs MLR analysis utilizing SPSS software to set an equation with calculated values for constant and SDGs indicators coefficients. The regression equation summarizes the linear relationship between REC and SDGs indicators as shown in Eq. 2.

$$
\begin{aligned}
REC = & -141.5 + 284.6X_{185} + 197.3X_{85} + 116.3X_{182} + 28.7X_{141} + 16.8X_{86} + 12.3X_{33} + \\
& 5.2X_{7} + 2.6X_{18} + 2.3X_{181} + 1.5X_{179} + 1.4X_{62} + 1.3X_{200} + 1.2X_{115} + X_{129} + X_{214} + 0.9X_{3} \\
& + 0.9X_{84} + 0.9X_{148} + 0.7X_{209} + 0.7X_{34} + 0.6X_{170} + 0.5X_{131} + 0.5X_{21} + 0.5X_{171} + 0.5X_{110} \\
& + 0.5X_{64} + 0.5X_{27} + 0.4X_{57} + 0.4X_{94} + 0.4X_{35} + 0.4X_{74} + 0.4X_{20} + 0.3X_{100} + 0.3X_{133} + \\
& 0.3X_{91} + 0.3X_{81} + 0.3X_{224} + 0.3X_{51} + 0.3X_{56} + 0.2X_{89} + 0.2X_{68} + 0.2X_{96} + 0.2X_{120} + \\
& 0.2X_{80} + 0.2X_{50} + 0.2X_{44} + 0.1X_{103} + 0.1X_{114} + 0.1X_{70} + 0.1X_{97} + 0.1X_{93} + 0.1X_{11} + \\
& 0.1X_{104} + 0.1X_{190} + 0.04X_{199} + 0.03X_{98} + 0.03X_{73} + 0.03X_{168} + 0.02X_{245} + 0.02X_{159} + \\
& 0.02X_{193} + 0.02X_{105} + 0.01X_{28} + 0.01X_{49} + 0.0002X_{136} + 0.0002X_{140} + 0.0002X_{149} + \\
& 0.0001X_{142} - 0.0009X_{135} - 0.01X_{223} - 0.03X_{36} - 0.03X_{119} - 0.04X_{90} - 0.04X_{194} - 0.1X_{63} - \\
& 0.1X_{121} - 0.1X_{78} - 0.1X_{32} - 0.1X_{117} - 0.1X_{172} - 0.1X_{61} - 0.1X_{43} - 0.2X_{187} - 0.2X_{158} - 0.2X_{16} - \\
& 0.2X_{160} - 0.2X_{54} - 0.2X_{99} - 0.2X_{52} - 0.3X_{196} - 0.4X_{83} - 0.5X_{69} - 0.5X_{92} - 0.6X_{125} - 0.6X_{116} - \\
& 0.6X_{95} - 0.6X_{22} - 0.9X_{40} - 0.9X_{118} - X_{53} - X_{127} - 1.5X_{132} - 1.6X_{45} - 1.8X_{207} - 3X_{186} - 3.3X_{46} - \\
& 4X_{67} - 8.9X_{66} - 44.6X_{184} - 68.4X_{17} - 141.3X_{183}
\end{aligned}
\tag{2}
$$

The response variable represents the REC, and the predictors (X_1, X_2, X_3, …... X_n) represent SDGs indicators. The determined regression equation offers a calculated value for REC in terms of 111 SD Indicators given in Eq. (2).

Results and discussions

Sustainable Development Index

Along with PCA results, SPSS software generates factor score values for each extracted component. The factor score is a numerical value mapping the variables of each component into one composite value. The study proposes the factor score value of PCA dominant component to be an SD Index as it explains 60% of SD country level. The study classifies countries according to the proposed SD Index, Table 4. mentions four categories of SD Index high, medium-high, medium-low, and low referring to the share of REC. A closer look at SD Index and REC values for each category, it is evident that most countries with a high REC have a low SD Index and vice versa. Pearson correlation coefficient is calculated to measure the strength and the direction of the relationship between SD Index and RE. The obtained Pearson coefficient value (– 0.672) describes an inverted linear association as shown in Fig. 4. Contrary to most previous studies that demonstrate a positive association between REC and SD indicators [31, 32]. The obtained strong inverse relationship provides evidence that the SD level is not sufficient to explain the increase in REC. The transition to renewable energy use in countries with a high SD Index occurs slowly as these counties already have conventional power plants and a solid infrastructure network for energy generation and transmission, so generating energy from renewable sources is not an essential need for providing a normal life. In such countries, renewable energy is generated for saving natural resources, improving environmental conditions, and reducing global climate deterioration [38]. On the other side, countries with a low SD Index are rapidly turning

Table 4 Examples of countries classification according to SD Index

Country	% REC	Factor score (SD Index)	Country	% REC	Factor score (SD Index)
High SD Index (greater than 75)			**Medium-high SD Index** (75–50)		
Norway	61	**100**	Romania	24	**74**
Denmark	36	**98**	China	12	**72**
Germany	15	**95**	Bosnia–Herzegovina	19	**70**
Austria	33	**94**	Georgia	30	**69**
Spain	16	**90**	Venezuela, RB	15	**67**
Portugal	25	**87**	Albania	37	**66**
Latvia	43	**85**	Tunisia	12	**65**
Hungary	14	**84**	Ecuador	17	**64**
Croatia	30	**83**	Peru	24	**60**
Uruguay	61	**79**	South Africa	12	**57**
Costa Rica	36	**77**	Morocco	12	**55**
Argentina	12	**76**	Egypt, Arab Rep.	10	**54**
Medium-low SD Index (50–25)			**Low SD Index** (less than 25)		
Namibia	29	**47**	Tanzania	84	**24**
India	28	**46**	Uganda	89	**24**
Bangladesh	41	**44**	Angola	56	**24**
Kenya	66	**39**	Afghanistan	25	**22**
Nepal	78	**36**	Benin	48	**21**
Zimbabwe	83	**34**	Nigeria	83	**21**
Rwanda	87	**31**	Liberia	85	**19**
Congo, Rep.	70	**31**	Mali	59	**19**
Lesotho	39	**30**	Ethiopia	87	**17**
Pakistan	29	**29**	Mozambique	59	**16**
Zambia	86	**27**	Congo, Dem. Rep.	97	**15**
Cameroon	79	**25**	Niger	73	**7**

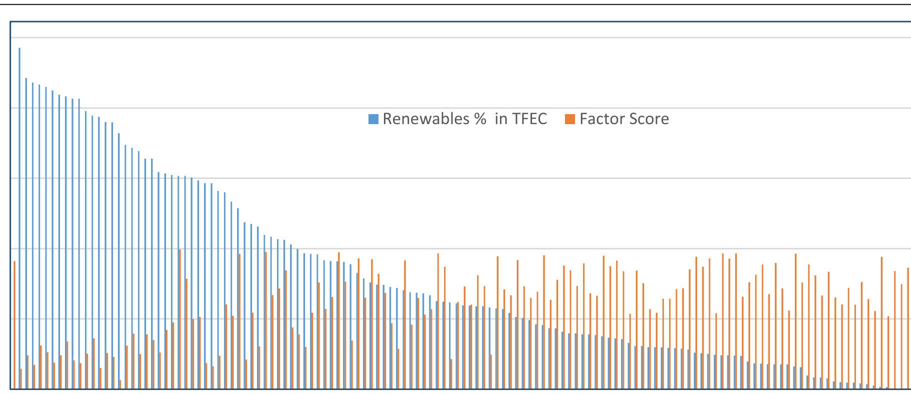

Fig. 4 Correlation (– 0.672) between SD Index, factor score, and REC

to the new clean energy as they do not own suitable fossil resources enough to comply with their energy needs and the infrastructure network is not proper and sometimes does not exist [39, 40].

Sustainable development indicators and REC relationship:

The determined regression equation Eq. (2) describes the mathematical relationship between each SDGs indicator (independent variables) and REC (the dependent variable) determining the perfect line to fit the relationship. Furthermore, the regression equation provides a calculated value for a country's REC in terms of SDGs indicators values. Analyzing the 111 SDGs indicators given in the regression equation, further explanations to the relationship between REC and SDGs indicators can be provided in the following points:

- The sign of the predictors is used to describe how an individual SDGs indicator change with REC; positive sign means direct relationship and negative sign means inverse relationship. The results indicate that 68 SDGs represent a direct relationship with REC, while 43 SDGs represent an inverse relationship with REC.
- The value of the predictor coefficient is used to evaluate the importance of individual predictors. SDGs indicator coefficient, which has a more significant positive or negative value, makes a more remarkable change in REC value. Likewise, the SDGs indicator coefficient that has a smaller positive or negative value makes a smaller change in the value of REC.
- The regression equation is used to adjust the individual predictors according to the sign and the value of the predictor coefficient to estimate the REC values in any year by changing the values of the predictors' indicators given in the regression equation.

Tables 5 and 6 show the SDGs indicator given in Eq. (2) that have a high positive and negative relationship with REC. Comparing indicators, that have appeared in the

Table 5 SDGs indicators that have a high positive relationship with REC

SDGs indicators with a positive (direct) relationship with REC			
$248.6X_{185}$	Inequality life expectancy index	X_{129}	Employment in industry, male
$197.3X_{85}$	Gender Development Index (GDI)	X_{214}	Forest area, change
$116.3X_{182}$	Inequality adjusted education index	$0.9X_{3}$	Birth rate
$28.7X_{141}$	Income index	$0.9X_{84}$	Contributing family workers, male
$16.8X_{86}$	Gender Inequality Index (GII)	$0.9X_{148}$	Old age dependency ratio
$12.3X_{33}$	Human Trophic Level	$0.7X_{34}$	Prevalence of stunting in children
$5.2X_{7}$	Population growth	$0.7X_{209}$	Energy-related CO_2 emissions
$2.6X_{18}$	SDGs Index Score	$0.6X_{170}$	Research and development expenditure
$2.3X_{181}$	Inequality in life expectancy	$0.5X_{21}$	Spillover Index Rank
$1.5X_{179}$	Inequality in education	$0.5X_{27}$	Population live in extreme poverty
$1.4X_{62}$	Subjective well-being	$0.5X_{64}$	Universal health coverage
$1.3X_{200}$	Forest rents (% of GDP)	$0.5X_{110}$	RE percentage of primary energy supply
$1.2X_{115}$	Financial account ownership, adults	$0.5X_{171}$	Scientific and technical journal articles

Table 6 SDGs indicators that have a high negative relationship with REC

SDGs indicators with a negative (inverse) relationship with REC			
$141.3X_{186}$	Overall loss in HDI due to inequality	X_{53}	Mortality rate, neonatal
$68.4X_{17}$	Human Development Index	X_{127}	Employment in industry
$44.6X_{184}$	Inequality-adjusted income index	$0.9X_{40}$	Immunization, measles
$8.9X_{66}$	Education index	$0.9X_{118}$	Financial account ownership, richest 60%
$4X_{67}$	Expected years of schooling	$0.6X_{22}$	Age dependency ratio
$3.3X_{46}$	Life expectancy at birth, male	$0.6X_{95}$	People using drinking water services
$3X_{183}$	Inequality-adjusted HDI	$0.6X_{116}$	Financial account ownership, poorest 40%
$1.8X_{207}$	Carbon dioxide emissions per capita	$0.6X_{125}$	Employment in agriculture, female
$1.6X_{45}$	Life expectancy at birth, female	$0.5X_{69}$	Expected years of schooling, male
$1.5X_{132}$	Employment in services, female		

regression equation to previous literature results, has found that the environmental dimension characterized by CO2 emissions has a negative relationship with REC. Hence, the use of renewable energy contributes to improving the environment as stated in most previous studies [19–30]. Regarding the economic dimension, most previous studies have mentioned the positive relationship between GDP and REC [32–38], while the current study demonstrates that GDP has no relationship with REC meantime the results indicate a positive relationship between Income Index and REC. A positive correlation between service and industrial value-added and REC is indicated in both the current results and a former study [35]. Previous studies signify a positive correlation between the education level [43], income inequality [41], HDI [45], public health expenditure [37], adjusted net savings [44], and REC. On the other hand, the results indicate a negative correlation between the education level characterized by Education Index, income inequality represented by Inequality-Adjusted Income Index, HDI, and REC, and no relationship appears between adjusted net savings, public health expenditure, and REC.

The extracted indicators make a significant change in REC value when their value change, meaning that to increase the REC, it is helpful for planners and decision-makers to consider these indicators.

Estimated renewable energy consumption

The study uses the determined regression equation Eq. (2) to calculate the estimated value of REC for the 137 tested countries in terms of SDGs indicators values. Pearson correlation coefficient is calculated to investigate the connection between estimated REC and the concluded SD Index (Factor Score), The values of the estimated REC have a positive weak relationship (+ 0.25) with the SD Index. The range of the estimated REC values indicates that an increase in most countries REC should be considered except in the low SD Index category that the REC real value is greater than the estimated value as shown in Table 7.

Conclusions

Most existing studies have examined the relationship between SD and REC using economic and environmental indicators but only a few studies have included some social

Table 7 Examples of estimated REC according to SD Index

Country	EST_REC	SD Index	Country	EST_REC	SD Index
High SD Index (greater than 75)			**Medium-high SD Index** (75–50)		
Finland	**80**	98	Brazil	**77**	72
Sweden	**91**	97	China	**63**	72
New Zealand	**88**	93	Thailand	**78**	71
Cyprus	**61**	87	Jamaica	**48**	68
Hong Kong S	**57**	87	Panama	**66**	67
Greece	**70**	85	Venezuela, RB	**55**	67
Latvia	**96**	85	Mongolia	**43**	64
Emirates	**54**	85	Paraguay	**98**	61
Malaysia	**77**	76	Vietnam	**82**	57
Argentina	**66**	76	Bolivia	**56**	54
Medium-low SD Index (50–25)			**Low SD Index** (less than 25)		
Namibia	**61**	47	Cameroon	**64**	24
India	**64**	46	Togo	**65**	24
Cambodia	**88**	42	Mauritania	**45**	24
Myanmar	**80**	40	Uganda	**67**	24
Kenya	**65**	39	Malawi	**73**	23
Lao PDR	**79**	35	Afghanistan	**39**	22
Congo, Rep.	**65**	31	Nigeria	**74**	21
Sudan	**58**	31	Madagascar	**75**	19
Zambia	**84**	27	Sierra Leone	**67**	15
Cote d'Ivoire	**61**	26	Congo, Dem.	**73**	15

indicators. However, this study extends the literature on investigating the relationship between SD indicators and REC. A quantitative dedicative approach is adopted for setting a statistical model to test the proposed hypothesis, which suggests that REC is associated with a group of SD indicators and its value can be calculated in terms of these indicators. The statistical model, which consists of PCA and MLR that tests and utilizes data of 255 SDGs indicators from 137 countries, is employed to examine the REC-SD nexus.

The results, from the statistical tests, declare a further explanation for the relationship between REC and SDGs indicators. PCA results are (1) reducing data and extracting the dominant SDGs indicators, (2) concluding the SD Index, (3) classifying countries according to SD Index, and (4) determining the correlation between REC and SD Index. On the other hand, MLR results are (1) determining the relationship between SDGs indicators and REC, (2) evaluating the importance of each SGDs indicator, and (3) estimating REC value in a certain year by adjusting the SDGs indicators values.

The inverse correlation between REC and SD Index, which expresses the dominant factor representing collected data, explain the rapid transformation of low SD Index countries towards renewable energy technology. In low SD Index countries, many factors drive people to depend on renewable resources but the most forcing factor is the lack of a source of energy and the absence of transmission infrastructure due to many economic, political or natural obstacles.

The results. also. provide perceptible evidence of the relationship between REC and a set of SDGs indicators. In contrast, the importance of the individual SDGs indicators is varied according to the change they make in REC value. This variation provides planners and decision-makers with SDGs indicators that have the greatest importance (coefficients values) to obtain a more significant increase in REC value. For planners and decision-makers, the concluded regression equation, which represents the relationship between REC and a set of an integrated panel of SDGs indicators, is an effective optimization tool to increase the opportunities of providing societies with clean, modern and affordable sources of energy at the same time accelerating the development wheel.

Abbreviations
CO2: Carbon dioxide; PCA: Principal component analysis; GDP: Growth domestic product; REC: Renewable energy consumption; GHG: Greenhouse gas emissions; SPSS: Statistical Package for Social Sciences; HDI: Human Development Index; SD: Sustainable development; MLR: Multiple linear regression; SDGs: Sustainable Development Goals

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Authors' contributions
Each author has made substantial contributions to the conception and design of the work. R.H. has prepared the original draft, conceptualization and methodology, has performed the data curation formal analysis and interpretation of data, has utilized the software, and has attained manuscript review and editing. T.A. has substantively revised the manuscript, has verified all data and materials, and has approved the submitted version. All authors have read and approved the final manuscript to be personally accountable for the authors' contributions.

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Availability of data and materials
The datasets used are available from the World Bank database [47], Human Development Data Center [49], and Sustainable Development Report 2021 [50]. The combined dataset is available to the authors.

Declarations

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Not applicable.

Consent for publication
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Author details
[1]Architecture and Regional Planning, Faculty of Engineering, Cairo University, Cairo, Egypt. [2]Architecture Department, Faculty of Engineering, Cairo University, Cairo, Egypt.

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