Impact of Renewable Energy Utilization and Artificial Intelligence in Achieving Sustainable Development Goals

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Impact of Renewable Energy Utilization and Artificial Intelligence in Achieving Sustainable Development Goals

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Abstract

Many countries around the world are planning to reach 100% renewable energy (RE) use by 2050. In this context and due to the recent sharp increase in RE utilization in the global energy mix along with its progressive impact on the world energy sector, the evaluation and investigation of its effect on achieving sustainable development goals (SDGs) are not covered sufficiently. Here, we present an assessment of the emerging role of RE utilization and artificial intelligence (AI) toward achieving SDGs. A total of 17 SDGs were divided into three groups, namely, environment, society, and economy, as per the three key pillars of sustainable development. The RE has a positive impact toward achieving 75 targets across all SDGs by using an expert elicitation method-based consensus. However, it may negatively affect the accomplishment of the 27 targets. In addition, the AI can help the RE to enable the attainment of 42 out of 169 targets. With the current exponential growth of RE share and AI development together with addressing certain present limitations, this impact may cover additional targets in the future. Nevertheless, the present research foci neglect significant facets. The exponential growth of RE share and rapid evolution of AI need to be accompanied through the requisite regulatory insight and technology regulation to cover additional targets in the future.
Introduction

Issues concerning the utilization and supply of energy are not only related to global warming but also to environmental challenges, such as air pollution, forest destruction, ozone depletion, acid precipitation, greenhouse gases (GHGs), water and land use, wildlife loss, and radioactive emissions. In addition, the current energy supply has an impact on the economic and social sectors, thereby causing a range of pressing socio-economic challenges. These challenges need to be addressed together if humanity wants to reach a promising and brighter energy future with reduced environmental, economic, and social impacts. For this purpose and to overcome the well-known negative effects of conventional energy plants (i.e., coal, oil, and natural gas) on sustainability development, the world now turned to use these resources within some limit and turned the thinking toward renewable energy (RE) sources (i.e., wind, solar photovoltaic (PV), hydropower, geothermal, and biomass). With the use of RE sources, the environmental, economic, and social issues can be reduced because these options are considered to help achieve an environmentally sound technology; low electricity cost; job creation; improved health; community development, especially in rural areas and developing countries; no or little emission production of poisonous and exhaust gases, such as sulfur dioxide, carbon monoxide, and carbon dioxide. Therefore, the share of RE in the global energy mix has increased dramatically from 8.6% in 2010 and to 18.2% by the end of 2017 and then jumped to nearly 28% in the first quarter of 2020. In the same context, after years of development and evolution, artificial intelligence (AI) now began to affect our daily lives deeply and is beginning to have a noteworthy impact on the fields of sustainable growth and development. In line with this, the AI has an important role in the dramatic increase in RE utilization and contribution to the energy mix, as well as the potential to revolutionize the RE sector. The AI applications and approaches for developing the RE include safety and reliability improvement, cost reduction, strategies to reduce environmental and climate impacts, increase the energy efficiency, expand RE market, improve integration of microgrids (MG) and smart grid, produce more accurate predictions of RE, and optimal operation of RE sources. Therefore, based on the literature (Supplementary Data), the applications of AI for RE operation and utilization (AI-based RE) has always have a positive impact on RE utilization, and the negative impact is almost negligible.

The RE utilization and AI-based RE have a role in the future of sustainability either for long- or short-term. Based on the literature, the potential effects of RE and AI-based RE show positive effects on sustainable development while the RE utilization may have some negative impacts. Some recent studies focused on linking the relationship between the achievement of the 7th goal (affordable and clean energy) of the sustainable development goals (SDGs) and RE. However, no research article has systematically examined the degree to which RE utilization and AI based-RE could affect all facets of sustainable development-identified in this research as the 169 targets of the 17 SDGs agreed internationally in the sustainable development agenda 2030. This research gap is critical. Thus, it must be filled because we detect that the RE utilization could affect the capacity to achieve the 169 targets of SDGs.

Therefore, this study presents, discusses, and explores how RE can either affect the achievement of all 169 targets within the 17 goals which defined in the sustainable development agenda 2030 positively or negatively. Moreover, if the RE has an impact on a specific target, then we discussed and identified in case AI implementation has a role on RE for this specific target. Connections were defined by the processes outlined in the Method section at the last part of this research. The method can be characterized by means of an expert elicitation method-based consensus that is notified by earlier research targeted at the mapping of SDGs interlinkages. Moreover, we present an assessment attempt based on the published evidence, which is characterized as an enabler or inhibitor to identify the impact of RE utilization and development on the pursuit of the 17 SDGs and every one of its constituent targets. The evidence on the impact of AI utilization in RE is also investigated. A summary of the findings can be found in Fig. 1. In addition, the
Supplementary Data present a comprehensive list of all SDGs along with each of its constituent targets and the detailed findings and evidence of this study.

The RE sources considered in this study include wind, solar PV, hydropower, tidal, marine, geothermal, and biomass energies. With regard to AI utilization for RE sources, although the definition of AI is not internationally accepted, each software technology that has at least one of the following features was considered AI for this study: optimization (i.e., optimal operation of RE sources and efficiency enhancement), prediction (e.g., weather forecast), interactive communication (i.e., smart grids), automatic knowledge extraction (i.e., scheduling based on the price and whether conduction), and efficient problems solving (i.e., reduce cost and CO$_2$, modeling, availability prediction, and control of RE systems). Other sub-files, such as machine learning, are considered AI, and its impact on RE systems is also considered.

![Fig. 1 Assessment outline of the negative and positive impact of RE utilization, including AI, on different SDGs](image)

Reported evidence on the possibility for RE utilization on the 17 SDGs as (a) positive impact, (b) negative impact, and (c) application of AI
for RE as an enabler. Each of the 17 SDGs is represented by the numbers inside the colored sixteen-pointed star. The corresponding percentages for each SDG indicate the potential impacts of RE utilization, including AI, on achieving its targets. The findings related to the three groups as per the three key pillars of sustainable development, namely Environment, Society, and Economy, are also observed in the outer circle of the diagram.

**Assessment on the impacts of RE utilization toward achieving SDGs**

To assess the impact of RE and AI-based RE utilization on each of the 169 targets within the 17 SDGs in the 2030 agenda, we undertook a method designed to answer two questions: (i) Are pieces of evidence of the RE utilization role either positively or negatively toward achieving this particular target published? If yes, then the second question is (ii) Are pieces of evidence about the role of the implementation of AI to the RE systems toward achieving this specific target available? The review assessment of the related literature indicates that RE has a positive impact on 75 targets, which represent 44.3% across the entire SDGs. However, with the current exponential growth of RE share, this impact may cover additional targets in the future. Furthermore, 27 targets (15.8%, across the whole of SDGs as well) can reveal in the negative effect from the blooming of RE. Also, based on the literature and the assessment of relevant evidence, the AI has a positive impact on the RE utilization, such as improving the efficiency, operation, and production while reducing the cost and emissions. Thus, the role of AI use in RE has a positive role and may act as an enabler toward achieving 42 targets (24.85% of all SDGs), commonly, by technical enhancement, which can allow these existing limitations to be overcome. To organize the outcomes of this assessment, the SDGs are classified into three groups as per the three key pillars of sustainable development, particularly economy, environment, and society (Methods and Supplementary Data). The classification of the groups into the three domains enables the authors to have an accurate overview of the overall areas that have an impact on RE utilization and AI-based RE implementation. We also presented the outcomes obtained (Fig. 2) by weighting the appropriateness of the evidence provided in every reference to evaluate an affinity (the interlinking) with respect to the targets assessed (in percentage), as explained in the Methods section at the end of this study.
Fig. 2 Impact of the RE and the emerging role of AI for RE utilization in each SDG toward achieving the 17 SDGs. Sankey diagram summarized the positive impact, negative impact, and the role of AI for RE utilization for all SDGs (Table 1 in the Supplementary data). Thick and thin lines correspond to the high and low impact of each SDGs. The content in the figure does not represent the vision of the United Nations and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG: https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

**RE utilization and environmental outcomes.** Most researchers agreed that the RE projects have enhanced environmental impacts. For example, carbon dioxide gas elimination and climate change understanding within the world population and contribute toward achieving the related SDGs effectively. However, RE utilization with environmental impact has limited negative effect, especially in marine renewable sources. In this context, our assessment of relevant evidence indicates that within the environment group, 45 targets (45%) must benefit from the development and utilization of RE sources (Fig. 3). For instance, in SDG 13, on climate change, RE can act as a positive impact toward achieving 80% of its target effectively. Based on the evidence, the RE sources could act as an enabler toward achieving 50% and 25% of the SDG 13 and SDG 14 targets, respectively. Notably, the positive impact ratio (45%) would increase because of the continuous development of RE sources and its application to cover many sectors together with addressing certain present limitations. Benefits from RE for environment group (SDG13, SDG14, and SDG15) can be summarized on its ability to reduce the GHG produced from traditional fuels; minimize some kinds of air pollution; reduce climate-related hazards, such as CO₂ emissions; reduce the effects of ocean acidification; and many other benefits to the life, land, water, and forests to maintain the ecosystem. For instance, looking at targets 13.1 and 13.2, which calls to climate-related hazards and incorporate action on climate change into national strategies, strategies, and planning; many evidence confirmed that the utilization of RE resources will reduce the CO₂ emission in the power sector to approximately 70% by 2050 according to the plan published in the US, New Zealand, and Europe.
Additionally, to enhance the condition of ecosystems, AI applications can play an important role to help the RE in this regard. For instance, using some optimization methods will reduce the emission (target 15.1) in MG system that consists of five different RE sources to 8.1% using backtracking search algorithm and to 8.4% using particle swarm optimization in comparison to that without using these methods. One more example is target 15.2, which aim to manage all types of forests, this target can benefit from the using AI mapping techniques for RE potential maps to predict the proper locations for the expansion of RE source-based facilities and land protection. The optimized machine learning technique is used to enhance the battery based RE systems to reduce its degradation and environmental impact (13.1). Moreover, according to Dhunny et al., the genetic algorithm showed a good performance to find appropriate areas for the construction of wind turbines with negligible effects on forest, fauna, and flora, including migratory bird pathways, which is also consistent with target 15.9.

On the other hand, 10 targets of the SDGs within the environment group, which represent 37%, may be affected negatively from the development of RE. However, their consideration is crucial. In this regard, the most negative impacts come from marine RE. In particular, tidal energy may act as an inhibitor for (15.4) target when established on coastal estuaries or bays, and tidal barrages can cause major ecological effects on bird feeding areas. Moreover, wave energy and offshore tidal stream energy collectors, including mid-water column, floating, and seabed mounted devices, with a range of moving-part configurations resulted in a particular complex of possible environmental impacts for each device category. Also, marine RE may have a negative effect toward achieving the target 14.2 because these sources may increase underwater noise and collision risk and during day-to-day operation, underwater noise, electromagnetic field emissions and collisions or avoidance with the energy constructions represent further possible influences on coastal species, particularly in large predators. Furthermore, the large-scale wind farm and solar energy in some countries take large space thereby leading to the cutting of trees and using of agricultural lands. Therefore, they acts as an inhibitor of achieving target 15.2, and sub-target of 15.1 and 15.11. Overall, the RE may have a negative effect on forests, wetlands, mountains, and drylands. Existing evidence base is greater for some pathways (e.g., hydropower and bioenergy) than others (e.g., wind, solar, geothermal, and ocean), and the point remains that the large-scale distribution of RE may have some biodiversity tradeoffs.

**RE utilization and social outcomes.** The development of RE may also positively affect the attainment of several numbers of the SDGs in the Society group. In this context, from a total of 82 targets within this group, 33 targets (41%) can be benefited from the RE source development. However, negative impacts are identified with regard to 11 targets (41%). Moreover, the emerging role of AI for RE utilization can contribute toward achieving 23 targets (28%) (Fig. 4). Importantly, based on the classification of the 17 SDGs into three groups, SDGs within the Society group include SDGs (1-7), SDG 11, and SDG 16. Looking...
at SDG 7 (Affordable and Clean Energy), a clear evidence shows that the utilization of RE sources will act as an enabler toward the achievement of all targets (100%) within this goal without any negative impact. Moreover, the AI will affect the five targets (100%) within SDG 7 positively because of its ability to improve the operation, efficiency, and development of RE to reduce the energy cost and emissions. For instance, Wang et al., reported that by 2050, the costs of RE was projected to be much lower than non-RE52. Furthermore, the utilization of RE resources will reduce the CO\textsubscript{2} emission in the power sector to approximately 70% by 2050\textsuperscript{30}. Concerning AI role, the digital and intelligent energy systems, drawing on the ever-increasing data on energy demand and supply, identifying who needs energy and who to supply it at the right time, in the right place, and at the lowest cost will be possible.\textsuperscript{43} Moreover, AI plays an important role to reduce cost according to smart scheduling based on the weather condition to guarantee the continuous power supply and to enable consumers to respond to load management signals when operated under the supervision of a scheduling coordinator\textsuperscript{44}. As an example, the fulfilment of target 7.2, calling to boost substantially the quota of RE in the global energy mix, strong evidence of the RE source utilization to achieve this target. In this regard, the share of RE in the global energy mix was 8.6\% in 2010 and increased to 18.2\% by the end of 2017 and then jumped to nearly 28\% in the first quarter of 2020 from 26\% in 2019 and expected to rise to 45\% by 2040. Furthermore, in 2018, the RE produced at least 1 GW of generating capacity in more than 90 countries, whereas at least 30 countries exceeded 10 GW of capacity across the globe.\textsuperscript{37} These pieces of evidence confirmed without doubt that RE utilization contributes toward achieving this goal. In addition, toward achieving SDG 4, especially targets 4.1 and 4.4, this continuous growth of RE leads to the development of the industry and what RE’s potential can mean for creating jobs and speed up economic development.\textsuperscript{5} Moreover, RE-based remote teaching (schools and institutes electrified by RE) would allow educating more students in underdeveloped countries with improved performance.\textsuperscript{45,46} Several youth and adults can work in this sector, as well as direct youth toward income-generating activities in this sector because of the establishing of RE factories and prosperity of the RE industry.\textsuperscript{47} The RE development can have a positive and tangible impact on jobs because this energy is local in nature and can generally be made accessible without heavy infrastructure being available.\textsuperscript{48} In sum, based on the published evidence, the following social benefits, namely, local employment, job opportunities, improved health, and consumer choice, can be achieved as results of RE development.

Moreover, AI could support the use of Smart Grids, which in turn could increase the penetration of RE in the system.\textsuperscript{59} One more example, the advancement of RE can contribute toward achieving target 6.4 via the use of solar PV energy and/or hybrid RE in pumping the water from the underground wells in the rural and desert areas and thus decrease the number of people who suffer from water shortages.\textsuperscript{50,51} The AI can also be used for managing the water pumping via an efficient way for irrigation systems using optimization methods as proved by Chaouali et al.,\textsuperscript{52} who developed the fuzzy logic optimization to increase the efficient use of water and reduce water waste. One more example, the RE can act positively to target 6.1 called to universal and equitable access to safe and affordable drinking water for all. In this regard, the World Health Organization\textsuperscript{53} estimates that 760 million people around the world do not have access to clean drinking water, and the areas with the greatest water scarcity are generally off-grid, remote, and have high solar irradiation. Therefore, a standalone hybrid PV/wind energy system is used as an effective solution to continuously power a submersible water pump (underground well) to produce drinking water.\textsuperscript{54} For SDG 11, the using of AI in smart cities is going to improve the cost-effectiveness of new and existing energy infrastructure and increase the quality of life.\textsuperscript{54} On the other hand, some evidence found that RE utilization may act as an inhibitor toward achieving some targets or sub-targets within the Society group, including 1.2, 1.4, 3.9, 4.4, 4.9, 6.6, 11.1, 11.8, and 16.2. However, no negative impact was found within SDG 2, SDG 5, and SDG 7 (Supplementary Data) (Fig. 4). In this context, as for example, looking at target 3.9, called to decrease the diseases and deaths related to toxic substances and pollution of air, soil, and water, RE source, such as biomass may act as inhibitor for this target, because it releases carbon monoxide, leading to headaches, nausea, dizziness, and in high concentrations which may lead to premature death.\textsuperscript{55,56} One more example is related to target 6.6 in which there is weak evidence that the installation of RE farms such as solar, wind, biomass, and hydropower may affect the water-related ecosystems such as forests, wetland,
and mountain/valleys especially large scale RE farms. For instance, cutting the wood for biomass energy operation, using the wetland for solar/wind farms installation, etc.

**RE utilization and economic outcomes.** The remaining group or category of SDGs, which are relevant to the Economy, is described in Fig. 5. The five SDGs within the Economy group are relevant to decent work and economic growth, industry, innovation and infrastructure, reduced inequality, responsible consumption and production, and partnerships to achieve the goal (SDGs 8, 9, 10, 12 and 17, respectively). With respect to the economic group, we have identified that the RE utilization could positively help in achieving 30 targets (50%) out of the 60 targets within this group. The utilization and deployment of RE offer economic opportunities from using direct labor from remote communities, local materials and enterprises, local owners, and local banks’ services. Furthermore, the projects of RE have facilitated the communities by setting up a trust fund to invest the money earned by the sale of energy to the local economy. Looking at SDG 8, economic growth, and decent work, the current studies demonstrate that increased RE deployment contributes to the creation of economic development and jobs in manufacturing and structures. Based on the policy intervention enacted in different nations, jobs may grow from a few thousand to more than one million by 2030. The jobs created due to RE development are expected to compensate the loss of jobs in sectors, such as fossil fuels sector, because the ones involved in the supply chain of RE are typically more dispersed and labor intensive than the traditional energy market. For example, solar PV creates approximately twice the amount of jobs as compared with coal or natural gas for every unit of electricity produced. The achievement of target 8.3 can benefit from RE to create new jobs. For instance, the RE added approximately 7.7 million jobs across the globe in 2014, which was led by China with approximately 3,390 jobs, based on IRENA report 2016. Likewise, the transition to RE may show a positive impact on the Dutch economy and is expected to create almost 50,000 new jobs by 2030.
and adding almost 1% of GDP\textsuperscript{61}, which act positively on target 8.1 as well. In line with these facts, Table 1 shows the expected effects of the development of RE resources on the economic sector in some countries.

![Economy Diagram](image)

*Fig. 5 Thorough evaluation on the effect of RE utilization at the SDGs within the Economy group [SDGs (8-10), SDG 12 and SDG 17]. Reported evidence with respect to the positive/negative impact of the using of RE sources together with the emerging positive role of AI for RE utilization of each of the targets within this group. The content/colors in the figure do not represent the vision of the UN and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG.*

The RE options may considerably enhance the performance of rural small- and micro-enterprises. In this context, the use of RE emerges in the market for a rural house, biogas, and hydropower for rural entrepreneurship and government programs led to greater attention financing, involving small-scale market facilitation organizations, private power developer, and donor assistance, which may contribute toward achieving target 9.3\textsuperscript{62}. Many evidences found from our search confirm that the RE will positively impact the innovation, industry, and infrastructure (SDG 9). Moreover, concerning SDG 17, the RE may help in achieving some targets within this goal, such as strengthening domestic resource mobilization as RE diversity of sources began to widespread application, including developing countries\textsuperscript{63}, thereby offering a new policy of taxes with respect RE technology to encourage investment by citizens/individual or companies, and many organizations have established many RE projects, such as PV power plant for rural and remote areas in the developing countries\textsuperscript{64}, improving the global partnership for sustainable development as the RE sector witnessed global collaboration in term of research, financial support, and economic aspect\textsuperscript{65}.

The emerging role of AI for RE utilization may help it achieve some targets (22%) within the economy group because (a) the AI, machine learning, and smart communication can be used to succeed this harmonization effort to have unique standards and requirements concerning RE integration around the world\textsuperscript{66,67} (target 17.14 and 17.6); (b) improvement and optimization (using AI) will enhance the RE efficiency and production\textsuperscript{68,69} (target 12.11); (c) optimization of the waste to energy (WtE) technologies for treating of various waste fractions in a medium-term future energy system considering their complex properties and optimizing both investments and production. Optimization of routes, which include waste components (i.e., food and yard wastes, non-biodegradable components, rubber, plastic, textile, leather, and wood) are the optimized WtE routes for maximum power generation potential by biochemical and thermochemical treatments of solid waste\textsuperscript{70,71} (targets 12.4, 12.5); and (d) the AI, machine learning, optimization, and smart communications have positive impact to increase RE productivity, reduce the cost, and introduce innovation toward smart grid\textsuperscript{72-74} (target 8.1). Furthermore, fewer targets within the Economy group (6 targets, 10%) can be impacted negatively by RE. For instance, we have found evidence which confirmed that no remarkable causal link is found between RE consumption and total factor productivity (TFP) growth in the BRICS\textsuperscript{75}. Marine RE can have detrimental environmental effects because of the danger of collision, habitat destruction, noise, and electromagnetic fields of RE devices\textsuperscript{71}. 
Table 1: Expected economic effects of the development of RE resources in some countries.\(^{58}\)

<table>
<thead>
<tr>
<th>Region/country</th>
<th>Economic intervention assessed</th>
<th>Employment impact</th>
<th>GDP impact</th>
<th>Year foreseen</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Union</td>
<td>Reduction of GHG by 40% in 2030</td>
<td>+1.25 million (+0.5%) economy-wide jobs</td>
<td>+0.46%</td>
<td>2020</td>
</tr>
<tr>
<td>USA</td>
<td>RE role toward power grid Decarbonization</td>
<td>From +0.5 million to +1 million net job</td>
<td>+0.6%</td>
<td>2030</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Greater role of offshore wind rather than natural gas</td>
<td>+70,000 net job</td>
<td>+0.8%</td>
<td>2030</td>
</tr>
<tr>
<td>Japan</td>
<td>Incorporation of 23.3 GW of solar PV</td>
<td>n/a</td>
<td>USD 47.5 billion (+0.9%)</td>
<td>2030</td>
</tr>
<tr>
<td>Germany</td>
<td>Economical and broad goals for the RE deployment</td>
<td>+1% new jobs</td>
<td>To more than 3%</td>
<td>2030</td>
</tr>
<tr>
<td>Mexico</td>
<td>Incorporation capacity of 21 GW from renewable power</td>
<td>134,000 in power sector</td>
<td>+0.2%</td>
<td>2030</td>
</tr>
<tr>
<td>Ireland</td>
<td>Meet the 2020 wind goal</td>
<td>From (+1,150) to (+7,450) net employment</td>
<td>From (+0.2%) to (+1.3%)</td>
<td>2020</td>
</tr>
<tr>
<td>Netherland</td>
<td>Transition to 100% RE by 2050</td>
<td>+50,000 new job</td>
<td>+1%</td>
<td>2050</td>
</tr>
<tr>
<td>Chile</td>
<td>In power generation, 20% renewables (excl. big hydro)</td>
<td>+7800 jobs (+0.09 %) both direct and indirect</td>
<td>USD 2.24 billion (+0.63%)</td>
<td>2028</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>Adding capacity of 54 GW of renewable power</td>
<td>+137,000 in power sector</td>
<td>USD 51 billion (+0.4%)</td>
<td>2032</td>
</tr>
</tbody>
</table>

Role of AI in RE utilization

The emerging role of AI for RE utilization may help the latter to achieve some targets within the Environment, Society, and Economy groups by 22%, 28%, and 23%, respectively as shown in Fig. 1 (c). This due to the ability of AI to improve the operation and efficiency of RE sources and reduce the cost of operation and produced energy as well as minimize their environmental impacts efficiently.\(^{9,76,77}\) Given that the intermittency and ambiguity of RE supply are major concerns, emerging technologies, such as AI and machine learning provide plenty of opportunities to solve these concerns, because they are primarily intended for the processing of unknown data.\(^{79}\) Moreover, in developed countries, the power sector has already begun to use AI and related technologies that enable smart grids, smart meters, and the Internet of Things (IoT) devices to interact. Such technology can help enhance energy management, efficiency, transparency, and the use of RE sources.\(^{79}\) This step helps the RE to achieve many targets (i.e., 100% of SDG 7 targets). Furthermore, the role of AI applications can cover different areas of RE system, such as forecasting, emission reduction, cost-minimizing, robust and smooth control, high power quality without fluctuation even when input is intermittent, expansion of novel technologies for the optimal production from available natural resources, awareness of the environment, enhanced energy management, distribution of energy, and energy delivery.\(^{80,82}\) For instance, an optimal scheduling controller that uses AI optimization reduced the cost and emission in a micro-grid system that consist of different RE sources by 2.6% and 8.1%, respectively.\(^{32}\) It is founded that, AI utilization in RE can assist in achieving the future goals of the RE by developing accurate strategies in the control, simulation, decision, and optimization of RE systems. Towards achieving the SDGs, the use of AI in the RE based-power sector is now reaching emerging markets, where it may have a critical impact, as clean, cheap, and reliable energy is essential to development. The issues can be overcome over time by shifting knowledge of the power field to AI software firms. When properly designed, AI systems can indeed be useful in automating routine and organized operations, thereby helping people to address possible energy challenges in the future.\(^{83}\)
Toward sustainable RE Utilization

As mentioned above, the accelerated deployment of RE has currently been motivated primarily by a wide variety of goals (drivers), including the advancement of economic growth, enhancing the security of energy and access to electricity and alleviating climate change. As explained in Fig. 1 (a), the RE can achieve 100% of the SDG 7 target (Affordable and Clean Energy). However, toward sustainable RE utilization, the RE sources have addressed some limitation and its negative impact (illustrated in Fig. 1 (b) based on the published evidence). At present, we have no access to modern energy for 13% of the global population. In the same context, based on the UN report, electricity is still unavailable for one in seven people, and the bulk of this population lives in the world’s developing rural areas. Therefore, the development of RE resources is theoretically enough to generate electricity and then fill the current energy gap. In addition, the utilization of these renewable sources can contribute toward achieving many targets of the 17 SDGs and provide multiple long-term benefits, including job creation, energy security, economic prospects, environmental development, and global warming prevention. However, no clear vision in this regard is presented across the world, especially in terms of economic support (SDG 8) to date. The reason may be because no noteworthy causal link is found between RE consumption and total factor productivity (TFP) growth (target 8.2). In contrast with non-renewables, energy consumption engenders have favourable externality that leads to economic growth. Furthermore, the integration of RE sources into the electrical grid still suffer from the existence of unique standards across the globe to regulate its connection efficiently toward a secure, reliable, and economic integration. Moreover, the RE strategic policy shall cover four key aims: security of energy, social equity, economic benefits, and protection of the environment. Some studies concluded that despite the advantages of biomass as RE source, its utilization may act as an inhibitor for the target (3.9) because it releases carbon monoxide, thereby leading to headache, dizziness, nausea, and premature death. In addition, the biomass and other sources, such as solar farms, can affect the ecosystems (target 6.6) because of cutting the wood for biomass energy operation and using the wetland for farms installation. Therefore, an urgent solution to these negative effects should be addressed. Furthermore, the marine RE could have negative environmental impacts with respect to SDG 14 (life below water), thereby resulting from habitat loss, collision risks, noise, and electromagnetic fields of the RE devices. The marine RE can affect SDG 14 and SDG 15 through (a) increased underwater noise and collision risk; (b) during day-to-day operation, underwater noise, emission of electromagnetic fields and collision or avoidance with the energy structures represent further potential impacts on coastal species, particularly large predators; (c) offshore wind energy and tidal energy may cause a small amount of acidification during the construction, operation and/or decommissioning; and (d) inspite of the fact that wind energy system is low-polluting, it involves spatial tension and can have an effect on ecosystems, including fish, aquatic mammals, and birds. Therefore, toward sustainable RE development and toward achieving more SDG targets, these negative impacts and limitations of RE should be addressed.

Methods of the Study

This section describes the procedure used to achieve the findings reported in the current study and conducted in the Supplementary Data. The main aims of this study were to discuss and explore how RE can either affect the achievement of the adopted 2030 agenda positively or negatively for sustainable development that includes 17 SDGs with their 169 targets. Moreover, if the RE has an impact on a specific target, then we discussed and identified the role of the AI implementation on RE for this specific target. Toward this goal, we performed an expert elicitation procedure focused on consensus, advised by previous research on the interlinkage mapping of SDGs. The writers of this research are part of the academic field that covers a wide assortment of fields, especially with regard to energy, engineering, environmental, and natural sciences, which serve as experts within the elicitation technique. To support the established linkage between RE and AI utilization for RE with the 169 targets, the authors conducted an expert-driven academic publication search. In this search, the following sources of knowledge were deemed to be appropriate
evidence: (a) research published on actual-international applications provided that the analyzed publications have adequate quality; (b) research published on laboratory/controlled eventualities provided that the publications taken into consideration within the evaluation have been of adequate quality; (c) published data, reports, and published evidence from authorized/accredited organizations, such as government bodies and UN; and (d) applications recorded on the commercial level. The following resources of knowledge were not deemed to be sufficient proof: (a) actual-international applications with lack of peer-reviewed study; (b) media; (c) public beliefs; (d) educated assumptions; and (e) other means of knowledge.

**Expert elicitation process.** In this stage, one or more key contributors were assigned to particular SDGs. However, in certain cases, the same SDG was assigned to more of other contributors (see the supplementary data in which the initials fit names of the contributors). To this end, the first search was carried out by the first contributor, and the additional contributor added the analysis. In some cases, the first contributors added the analysis along with the additional one. The authors have made an effort to search for each target and provided the pieces of evidence which have adequate quality if any. When the assessment is finished for each SDG, a reviewer/s evaluated the contact and causes. The reviewers’ key contribution is to assess the study objectively and provide alternate points of view. Finally, a broad discussion for the outcomes with respect to every single goal between the contributors and reviewers was carried out recursively until the assessment for the 17 goals was fairly perfect.

**Final analysis.** In this stage, after finding consensus on the assessment of the evidence for each goal (Supplementary Data), analyzing of the final results has been conducted by determining the number of targets for which RE utilization act positively, negatively, or if no evidence is found. Then, when the RE has a positive impact on a specific target, the following question is answered on the basis of the published evidence "Is there any role for AI application for helping the RE to serve as an enabler for this target?" and the number of targets in this regard is evaluated. Next, we evaluated the findings and measured the proportion (in percentage %) as a positive impact, negative impact, AI role, and no effects for every one of the 169 targets within the 17 goals (Fig. 1). The total impact in percentage base for each SDGs is illustrated by the lines in the Sankey diagram (Fig. 2, based on the final results of Table 1 in the Supplementary data) in which the thick line mentions to the high impact, and thin line indicates the low impact. The 17 SDGs were divided into three groups, including Environment, Society, and Economy, in accordance with the grouping/classifications described by Ref. 18,19. Observing the individual outcomes from each of these groups in Figs. 3–5 and Tables 3–5 in the supplementary file is possible. For each goal of each SDG, these statistics show whether any reported evidence has a positive or negative effect, and the positive role of AI application in RE utilization were identified.

**Limitations of the research.** The investigation and assessment presented in this study reflect the authors' point of view. In addition, a few works of literature on how the RE and role of AI applications for RE utilization influence certain targets within the 17 SDGs could have been overlooked by the contributors or proof of such interlinkage could not be reported yet. However, the approaches were used to reduce the assessment’s subjectivity. For every interlinkage, several authors assessed, analyzed, and reviewed various published evidence on the impact of RE utilization and AI applications on RE sources carefully to highlight its delivery of every target, as discussed in the Section of the expert elicitation process above. Apart from that and based on the literature, the applications of AI for RE operation and utilization (AI-based RE) has always a positive impact on improving the RE utilization, and the negative impact is almost negligible. Therefore, even though the negative impacts in this regard are negligible, not taking this option in the assessment provided could be considered a limitation in this study. One more limitation is that the RE used in this analysis is limited to the power generation resources, such as PV, wind, geothermal, biomass, hydropower, and marine energies. Lastly, this research is based on SDGs analysis. The SDGs offer a strong perspective to look at globally defined objectives on sustainable development and provide a path forward for reflecting all aspects of sustainability, including social sustainability, human rights, environmental
development, and economic outcomes. However, the SDGs, are a political settlement and could be restricted to describing a few of the dynamic complexities and cross-interactions among different targets. Consequently, it must be taken into consideration as a complement along with former, existing and other international norms in place of a replacement 15.

**Data availability**

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

**Code availability**

The analysis code and the examined cases that validated our method are available from the corresponding authors upon reasonable request.

**References**


54 Yang, J. et al. Key index framework for quantitative sustainability assessment of energy infrastructures in a smart city: An example of Western Sydney. Energy Conversion and Economics.
60 IRENA. (International Renewable Energy Agency Abu Dhabi, United Arab Emirates, 2016).


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Author contributions

M.A.H. and A.Q.A designed the research. A.Q.A., M.A.H., P. J. K and R. A. B conducted data collection, analysis and written the manuscript. K.P.J., R.A.B., M. M., S. A. R., Z. Y. D., S. K. T., T. M. I.M. and K. M. M provided study oversight and edited the manuscript. All authors discussed the results and commented on the manuscript.

Competing interests

The authors declare no competing interests.
Assessment outline of the negative and positive impact of RE utilization, including AI, on different SDGs. Reported evidence on the possibility for RE utilization on the 17 SDGs as (a) positive impact, (b) negative impact, and (c) application of AI for RE as an enabler. Each of the 17 SDGs is represented by the numbers inside the colored sixteen-pointed star. The corresponding percentages for each SDG indicate the potential impacts of RE utilization, including AI, on achieving its targets. The findings related to the three groups as per the three key pillars of sustainable development, namely Environment, Society, and Economy, are also observed in the outer circle of the diagram.
Figure 2

Impact of the RE and the emerging role of AI for RE utilization in each SDG toward achieving the 17 SDGs. Sankey diagram summarized the positive impact, negative impact, and the role of AI for RE utilization for all SDGs (Table 1 in the Supplementary data). Thick and thin lines correspond to the high and low impact of each SDGs. The content in the figure does not represent the vision of the United Nations and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG:https://www.un.org/sustainabledevelopment/sustainable-development-goals/.
Thorough evaluation on the effect of RE utilization at the SDGs within the environment group (SDGs 13, 14, and 15). Reported evidence with respect to the positive/negative impact of RE sources together with the emerging positive role of AI for RE utilization of each of the targets within this group. The content/colors in the figure do not represent the vision of the UN and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG:https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

Figure 3

Figure 4
Thorough evaluation on the effect of RE utilization at the SDGs within the Society group [SDGs (1-7), SDG 11 and SDG 16]. Reported evidence with respect to the positive/negative impact of the using of RE sources together with the emerging positive role of AI for RE utilization of each of the targets within this group. The content/colors in the figure do not represent the vision of the UN and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG.

Figure 5

Thorough evaluation on the effect of RE utilization at the SDGs within the Economy group [SDGs (8-10), SDG 12 and SDG 17]. Reported evidence with respect to the positive/negative impact of the using of RE sources together with the emerging positive role of AI for RE utilization of each of the targets within this group. The content/colors in the figure do not represent the vision of the UN and has not been reviewed by them. Moreover, the icons of SDG are courtesy of UN/SDG.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryInformationF.pdf