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Opportunities and Challenges for Renewable Energy Utilization in Pakistan

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Abstract: Pakistan is a developing country that faces severe energy crises due to the increased use of energy. The purpose of this study is energy transition by designing a strategy for the adoption of renewable energy policies in the entire energy system by using all renewable energy resources to forecast future energy needs and carbon emission mitigation potential. This research study aims to evaluate the renewable energy policies of Pakistan and to analyze the ways to secure energy sources in the future using LEAP. The study established a path for the transformation of the Pakistan energy system by considering the potential of renewable resources, the cost of the energy system, and the primary energy supply. The highest value of energy demand is noted for the 1st scenario, while the lowest emissions are noted for the 16th scenario for each renewable source (WIN16, SOL16, and BIO16). The lowest values of energy demand and emissions (192.1 TWh and 37.7 MMT, respectively) are shown using the green solution compared to other scenarios (hydro, nuclear, BAU), concluding that the green solution is the most suitable scenario. The analysis shows, that from a technological and economic perspective, it is possible to carry out transformation with the necessary steps to effectively achieve a renewable energy system. The findings of this study show that the green scenario in Pakistan which has the lowest operational and externality costs is the best choice for the future.

Keywords: wind energy; solar energy; biomass energy; hydel energy; green energy solution; LEAP

1. Introduction

Socioeconomic development depends on energy streams. Global energy consumption is increasing, and the growing energy demands of Pakistan are being fulfilled by a combination of fossil fuels, renewable energy sources, and nuclear energy. Pakistan has been suffering from energy crises since 2007 [1] due to the imbalance in the supply and demand of electricity [2–4]. The combustion of fossil fuels produces harmful emissions that cause global warming, environmental pollution, and climate change [5,6]. Due to the shortage of fossil fuels in the coming decades, they are becoming expensive and limited. Pakistan is focusing on the exploitation of native and environmentally clean energy sources. The promotion of clean and renewable energy is one of the suitable alternatives to meet current and future energy demands [7]. Various government organizations have been established to promote the implementation of renewable energy technologies for the reduction of CO_2 emissions [8]. The challenge is how to accomplish these goals while contemplating energy prices, the availability of resources, and cross-country partnerships.

Pakistan is a developing country and imports most of the fuels to meet the increase in energy consumption [2,9]. The growing demand for energy and consumption shows that energy is one of the biggest future problems of the world [10]. In 2018, the total installed capacity of electricity in Pakistan increased to 33,554 MW. However, last year, consumption increased to 106.927 GWh from 95,530 GWh [11,12]. Unfortunately, the economy of Pakistan is very much exaggerated due to the high dependency of its energy production systems on fossil fuels; as the price of fossil fuels is very high, it is promoting cost vulnerability [10,13,14].

Energy utilization has increased in the current decade, but an energy generation system has not been added to meet the required energy demand [11,15–17]. The high cost of electricity increases circular debt and subsidies [16]. Aside from the economy, studies have shown that the use of fossil fuels is causing environmental pollution and global warming [18]. The renewable energy options of solar and wind can fill these shortages in electricity without emitting greenhouse gases and poisoning the environment [19–21].

Various studies concentrate on the individual sources within the energy system such as solar, wind, biomass, and hydel for future development by the Pakistan energy sector [12,22–28]. Farooqui [29] reviewed the available potential of multiple renewable energy sources which include wind, micro hydel, solar, and biomass, and their existing and upcoming scenarios in the total energy mix, with certain suggestions. It is projected that in 2030, Pakistan will have the viable opportunity of a 30 GW setup of power from hydel and 50 GW power from wind. Mirza et al. [30] proposed a concept to find the barriers that bound the usage of renewable energy as a whole with the precise location of Pakistan and summarized the procedures to overcome these barriers. Peidong et al. [31] concluded the result of a renewable energy development policy includes laws, regulations, economic inducement, technical research and development, industrial support, and government model plans.

Few studies described solutions proposing a renewable energy system with low carbon emissions. Hansen et al. [32] proposed that research in the plan of 100% renewable energy systems in technical articles is impartially innovative but has attained great focus in the last decades. Furthermore, in refs. [21,33], authors searched various methods to obtain energy supplies in the future by reviewing the renewable energy policy, in particular solar energy, in Pakistan.

By investing in renewable energy resources, high dependency on fossil fuels can be avoided. From renewable energy resources, the total energy generated is almost 3857 GWh, while the installed capacity is 1637 MW in Pakistan [34]. By introducing renewable energy resources, many countries are strongly dealing with rapidly growing energy demand [35,36]. Many technologies of renewable energy are used to meet increasing energy demands and to decrease the inclination towards fossil fuels. They are also highly valuable when it comes to the environmental aspect of reducing greenhouse gas emissions. Pakistan is honored with abundant means of renewable energy resources. The credible outcomes of utilizing the renewable energy source assets of Pakistan incorporate solar, hydel, biomass, wind energy and so forth [2,9,16,30,37–39].

Renewable energy resources have been widely used to meet energy requirements during the last two decades, and their growth is now greatly increased. Three renewables (wind, hydropower, and solar) are greatly used to generate clean and sustainable energy compared to other renewables (geothermal, wave, tidal and biomass, etc.) [27,40]. The cumulative global installed capacity of solar, wind, and hydropower renewables has shares of 25.6%, 26.1%, and 47.6% of total global renewable energy, respectively, according to the IRENA report [41]. Moreover, the capacity in the percentage of different renewables such as onshore wind, offshore wind, hydropower, photovoltaic solar, and concentrated solar power has increased to 233, 810, 26, 883, and 274%, respectively, during the last decade (2011–2020) [41]. The Levelized cost of electricity is the lowest for onshore wind energy according to the IRENA report which makes this renewable energy option the most suitable among other renewable energy sources.

The main objective of the study is energy transition by designing a strategy for the adoption of renewable energy policies in the entire energy system of Pakistan. This study aims to achieve an entirely renewable energy system by using all energy resources to forecast future energy needs and carbon emission mitigation potential and utilization over the 22 years 2018–2040. Different scenario-based models are discussed and evaluated (BAU, RE scenario, HYD, NUC, and GR solution). The findings of these scenario-based models will describe a way forward for experts for controlling Pakistani energy setups to obtain a viable solution for future sustainability as well as clean energy and security for the energy sector in the future by executing a suitable path based on future economic development and political issues. Various techniques have been used in the past, but the scenario review used in this study provides numerous energy technology choices with a wide range from the present policy to the proposed green energy pathway. The goal of the scenarios is low carbon emissions and a reduction in energy demands until 2040. Scenarios are being established with a view to 2040 since this timeline is compatible with energy policies and allows ample time to introduce the proposed steps. This is important because, in a short time, improvements in energy infrastructure with long lifetimes are difficult to introduce.

2. Materials and Methods

LEAP is an advanced modeling method for tracking energy use, demand, and resource extraction across all sectors of the economy. It can help account for the sources and sinks of greenhouse gas (GHG) emissions taken from two sectors (energy and nonenergy). Emodi used a scenario-based study of the LEAP model to examine the future energy production, GHG emission, and supply of Nigeria from 2010 to 2040 [42]. Azam analyzed energy usage and emission forecasts using LEAP for road transport in Malaysia. The research included estimations of emissions of CO_2, CO, NOx, SOx, and volatile organic matter from 2012 to 2040 [43]. Pervaiz described the forecasting and planning of the energy sector paths of Pakistan to illustrate the future challenge by making three different scenarios on LEAP from 2011 to 2030 [24].

A demand tree in Figure 1 was made for the forecast of renewable energy resources (solar, wind, and biomass). Environmental loadings were applied to a specific fuel type as per carbon contents (software can predict accurate emissions). The step-by-step approach was used for the transition to renewable energy. In that consideration, a total of 52 scenarios were made for the Pakistan renewable energy policy. Different effects on energy consumption, utilization, and emissions were simultaneously estimated and compared. The design of a scenario explicitly informs about the consequences and impacts of certain policy implementations on a power sector.

2.1. Scenario Resources

To estimate the renewable energy capacity for Pakistan, a comprehensive literature and data review was performed to evaluate the available potential for the transition to a renewable energy system. The potential of resources varied between studies that suggested either theoretical, technological, economic, or limited potential. The main resources solar, wind, biomass, and hydel were analyzed with high shares in a future energy system.

The annual average solar insolation potential is 5.30 kWh/m^2 based on long-term measured data, and solar energy capacity is 175,800 GW using only 0.1% of the total surface area of the country (796,095 km^2) [2] as shown in Table 1. Solar potential is the same in all cities of Pakistan because solar radiation is equally distributed everywhere.

The ESMAP world bank has established a wind map that identifies the wind speed in different areas of the country with a total potential of wind over 130,000 MW. Sindh province is estimated to generate over 50,000 MW of potential wind. The coastal region of Pakistan is a perfect area for a wind power plant. The coastline of the country is 1000 km long [44]. The total installed wind power capacity is 792 MW, and the total wind power potential is 346,000 MW [45]. The wind resource assessment data of Pakistan [46] are shown in Table 2.
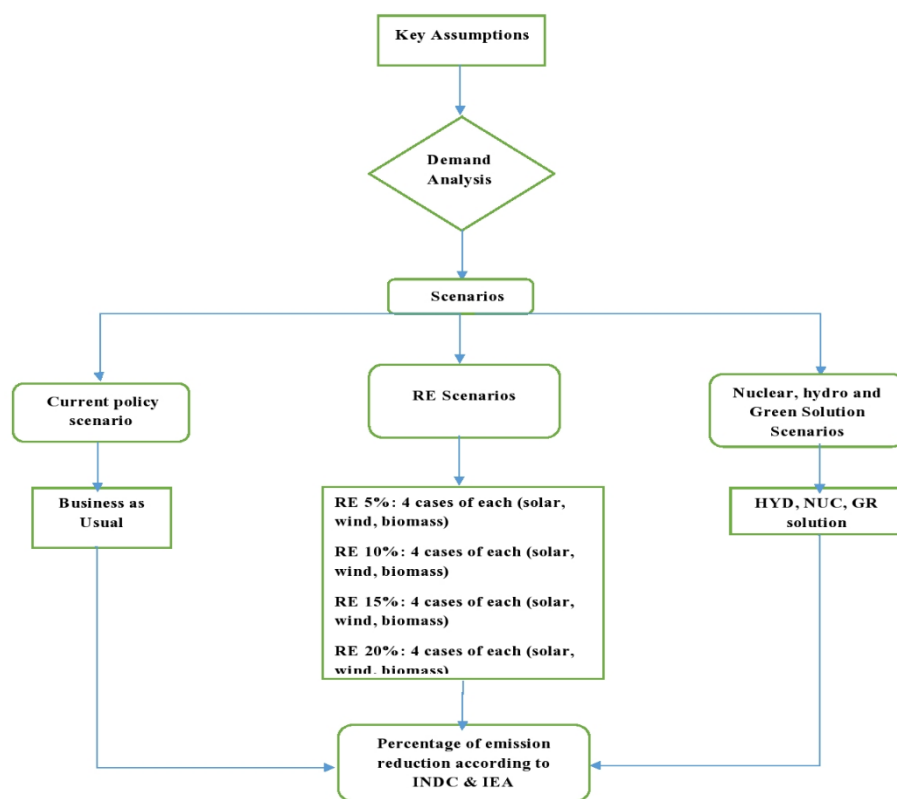
Figure 1. LEAP diagram for energy demand and emission.

Table 1. Available estimated potential of solar.

Metrological Stations	Annual Mean Daily Insolation (kWh/m^2)	Solar Potential (GW)
Islamabad	5.30	175,800
Karachi	5.30	175,800
Lahore	5.30	175,800
Multan	5.30	175,800
Peshawar	5.30	175,800
Quetta	5.30	175,800

Table 2. Available estimated potential of wind.

Province	Windy Land Area (km^2)	Windy Area (%) of Total Area	Potential Installable Capacity (MW)
Sindh	17,692	12.55	88,460
KPK	11,709	15.71	58,545
Balochistan	29,229	8.41	146,145
Total wind assessment of Pakistan	69,863	9.06	349,315

In an agricultural- and livestock-related scheme, Pakistan has approximately 50 million animals. On average, if 50% is collected for fuel, the daily waste generated from a bullock or bull (the most common animals kept in Pakistan) and a cow is about 10 kg; this amounts to 150 million kg, translating into around 12 million cubic meters of biogas. The available estimated potential of biomass is shown in Table 3, and the information related to the biomass potential of Pakistan can be referred to [47,48].

Table 3. Available estimated potential of biomass.

Types of Residues	Energy Potential of Residues GWh/year	Description
Cotton stalk	205,854	-
Wheat straw	138,324	Theoretical potential of
Rice straw	58,174	crop processing residues
Sugarcane trash	27,409	-
Maize stalk	19,229	-
Total	448,990	-
Bagasse	40,785	-
Rice husk	12,566	
Maize cob	5468	The theoretical potential of crop harvesting residues
Maize husk	3019	
Total	61,838	-

Hydropower is a primary household energy source. Pakistan has a hydropower capacity of almost 60,000 MW [49], most of which is in Gilgit-Baltistan (21,125 MW), KPK province (24,736 MW), Punjab (7291 MW), and Azad Jammu and Kashmir (6450 MW) as shown in Table 4.

Table 4. Available estimated potential of hydro.

Province	Projects in Operation (MW)	Projects with Raw Sites (MW)	Solicited Sites Projects (with Feasibility Studies) (MW)	Projects under Implementation			Total Hydropower Potential (MW)
				Public Sector	Private Sector		
					Province Level	Federal Level	
KPK	3849	8930	77	9482	377	2370	24,736
Gilgit-Baltistan	133	8542	534	11876	40	0	21,125
Punjab	1699	238	3606	720	308	720	7291
FATA	13			19	0	0	
AJK	1039	915	1	1231	92	3172	6450
Sindh	-	126	67	-	-	-	193

2.2. Modelling Tool

The energy system scenarios were developed by using advanced tools to analyze energy systems such as LEAP. This tool has been extensively used in the literature such as studies to design national energy policies, assess the mitigation of climate change, and assess the feasibility of a variety of technologies [50]. LEAP (Low Emissions Analysis Platform) is a comprehensive software for energy policy analysis. It provides accurate results and is used by energy policy experts in energy educational institutes, energy analysis agencies, and government organizations to develop future projections based on the input values of current policies and expected future growth rates in more than 190 countries [51]. LEAP can analyze energy demand as well as associated CO_2 emissions. Key assumptions for data are assigned in the measurements [52].

2.3. Scenario Building

Several long-term energy pathways are examined in this paper to demonstrate the various ways in which energy demand can be assessed. Scenario forecasting is a useful tool for developing a long-term energy infrastructure strategy to deal with unexpected future power demand. To efficiently analyze the uncertainties associated with energy, social and economic sectors, it highlights and promotes the integration of associated potentialities

having different varieties for two paths (policy and technical) [53]. Long-term energy paths in energy science describe various narratives that suggest a "collection of other potential hypothetical scenarios that can unfold in various ways" [54]. The impact of each pathway is rated and assembled using energy modeling techniques that are being evaluated.

Fifty-two different long-term energy scenarios were included: business as usual (BAU); RE: solar (SOL1-SOL16), wind (WIN1-WIN16), biomass (BIO1-BIO16); HYD; NUC; and GR solution scenarios. The assessment of scenarios begins in 2018 and concludes in 2040, while 2018 is taken as the base year. The 16 scenarios of each source were further divided into four cases (Case A, Case B, Case C, and Case D) with equal division of scenarios. The purpose was to avoid extensive results formation and repetition of the same kind of information in results and discussion. The LEAP software was used to analyze these diverse situations, an accounting energy modeling platform built upon the energy scenarios [52]. Each scenario was evaluated based on supply-side properties and assessments given the above facts that provide a set of specific energy policies. BAU scenario shows how much energy consumption and CO_2 emissions will increase if the same policy plans and forecast continue until 2040. As described earlier, 2018 is considered the base year so the values of all the renewable and conventional sources of energy were considered from the base year.

RE scenarios (renewable energy scenarios) were categorized into three types: solar, wind, and biomass. These scenarios were built to see how energy consumption and emission mitigation potential can decrease by limiting the share of conventional sources and maximizing the share of renewable sources to convert a system into a renewable energy system. The SOL, WIN, and BIO scenarios built under the RE scenarios were developed to investigate energy demand and CO_2 emissions. Sixteen scenarios were developed within SOL, WIN, and BIO scenarios for converting the system into a renewable energy system. Based on SOL, WIN, and BIO scenarios, from SOL1 to SOL16, WIN1 to WIN16, and BIO1 to BIO16 indicate that the energy demands and emission values were continuously decreasing, respectively. According to the RE scenarios, it is reported that the wind and solar energy sector (scenarios) require minimum energy and emissions, whereas higher energy and emissions are needed by the biomass energy sector (however, it remains at a lower stage than the BAU scenario).

Nuclear and hydro scenarios were established based on future projects. Hydro has a good share of energy power generation. If projects are completed soon then the share of hydro in power generation will increase to almost 15–20%. According to IAEA country nuclear power profiles, the country currently has five nuclear operating plants with a combined production of 1430 MW, while 2200 MW is under construction, and the almost 2.75% share of nuclear power will increase in coming years. Pakistan has committed to the international community in its intended nationally determined contributions (INDC) that the country will reduce its 2040 projected emissions by 20–25%. Renewable energy has less CO_2 emissions than fossil fuels. It is shown using the nuclear and hydro scenarios that emission reduction can occur using solar and wind renewables; however, the nuclear scenario has the highest needs (even higher than the BAU scenario). The minimum energy needs and emissions can be obtained using green solutions as observed from all the scenarios of the energy mix of Pakistan.

3. Results and Discussion

The energy systems of Pakistan in terms of scenarios are represented in this section (for each scenario) and summarized for a renewable energy system with reference to 2040.
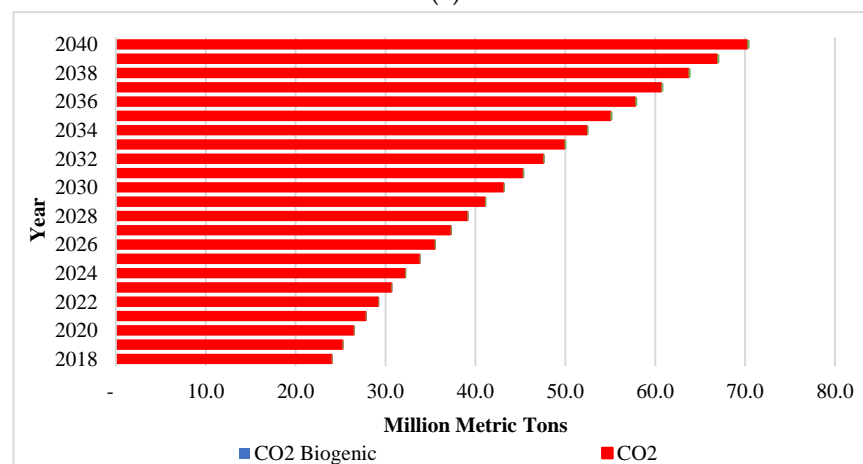
3.1. BAU Scenario

To analyze the transition to renewable energy resources, a business as usual (BAU) scenario was selected which depicts that CO_2 emissions and energy demand increase and reach 70.02 MMT and 301.8 TWh, respectively, if the same policies, plans, and forecasts continue in next 22 years. The results in Figure 2a,b show the detailed forecast of energy demand and emission values for 2018–2040. The emissions in terms of CO_2 are expected to

greatly increase (>70 MMT) until 2040. Other GHG emissions include CO_2 biogenetic, CO, CH_4, nonmethane volatile compounds, NO, NO_x, and S_2O, which are negligible in amount and are expected to remain the same in quantity until 2040.
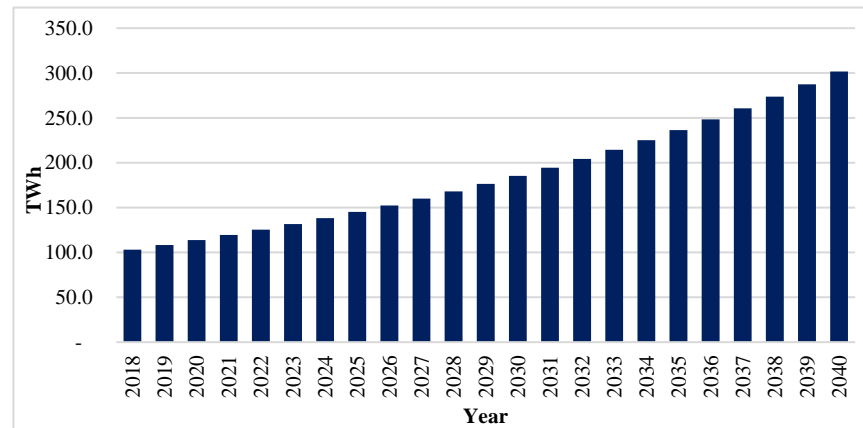
(a)

(b)

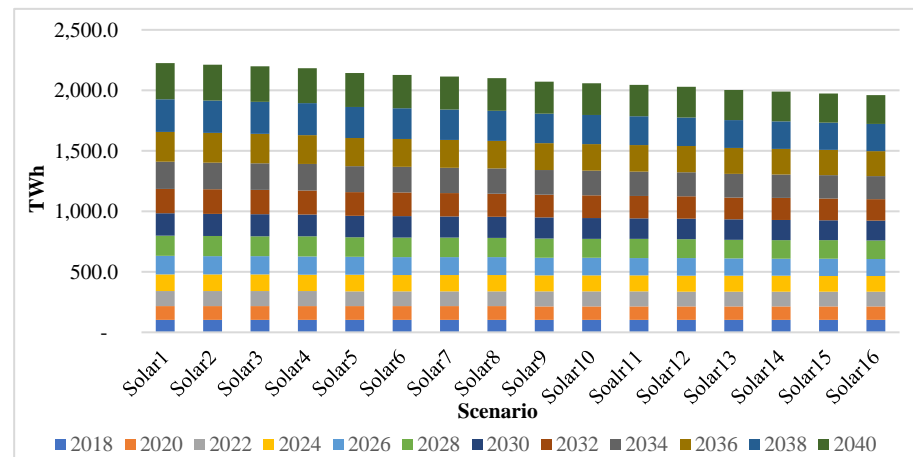**Figure 2.** (**a**) Energy demand of BAU scenario. (**b**) Emissions of BAU scenario.

3.2. RE Scenarios

Renewable energy is expected to grow to at least 15–20% of final energy demand by 2030 [55]. Energy demand and emissions are investigated for three different types of RE scenarios (solar, wind, biomass) with varying percentages of the energy mix for the relevant scenario. To analyze the energy demand growth and CO_2 emission reduction from the 20% share in the renewable energy model, the following three types of scenarios have been described.
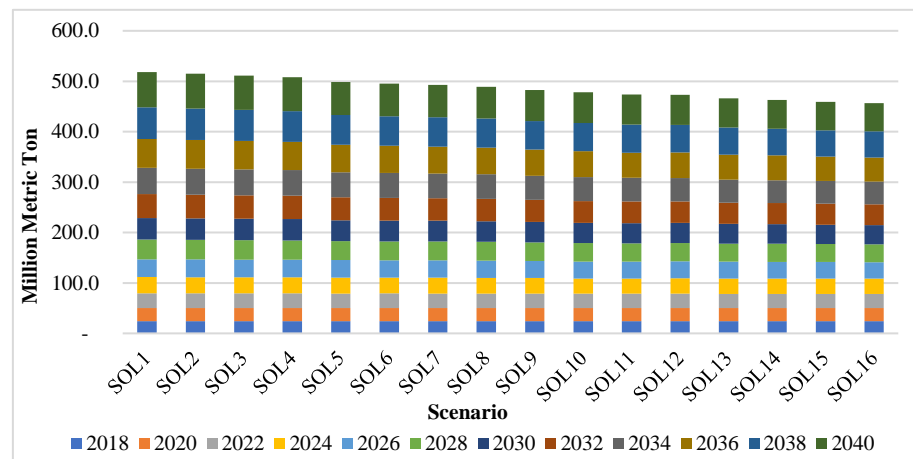
3.2.1. SOL Scenarios

The SOL scenarios built under the RE scenarios were developed to investigate energy demand and CO_2 emissions. Sixteen scenarios were developed within SOL scenarios for converting to renewable energy. Based on SOL scenarios, from SOL1 to SOL16 indicates that the energy demands and emission values were continuously decreasing so the source to focus on more is solar. To analyze the growth in energy demand and reduction in CO_2 emission values by considering different percentages of solar values, CASE A (SOL1-SOL4) depicts that the energy demand is 289.3 TWh, and associated CO_2 emissions are 67.6 MMT. Similarly, for CASE B (SOL5-SOL8), the energy demand is 270.6 TWh, and

the associated CO_2 emissions are 63.3 MMT. In CASE C (SOL9-SOL12), energy demand decreases and reaches 255 TWh, and the emissions are 59.7 MMT. The growth in energy demand and values of CO_2 emissions for CASE D (SOL13-SOL16) are 239.5 TWh and 56.0 MMT, respectively. The results in Figure 3a,b show the highest value of energy demand for SOL1, while the lowest emissions are for the SOL16 scenario with the highest percentage of solar. The continued decrease in energy demand and CO_2 emission is almost negligible until 2028, and notable variations are recorded after the year 2034. This change highlights that solar energy could be abundantly used in the coming years to mitigate climate issues and meet clean energy demand.


(**a**)

(**b**)

Figure 3. (**a**) Energy demand SOL1 scenario–SOL16 scenario. (**b**) Emissions of SOL1 scenario–SOL16 scenario.
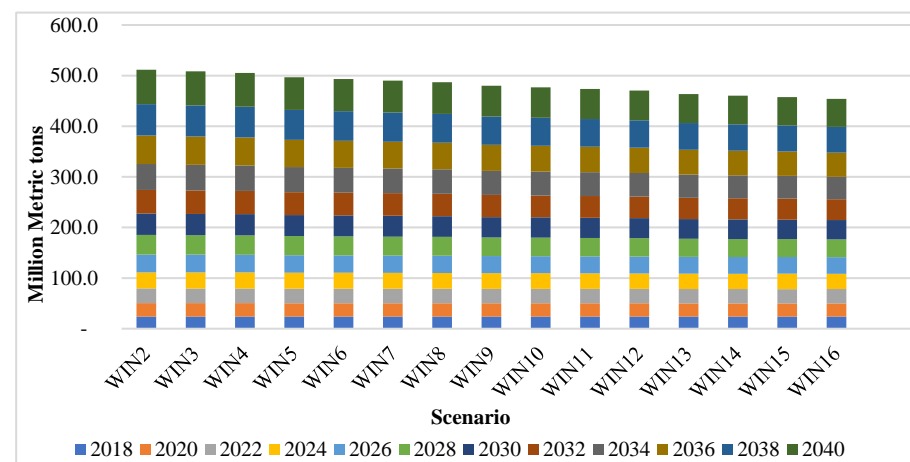
3.2.2. WIN Scenarios

The wind scenarios built under the RE scenarios were developed to investigate energy demand and CO_2 emissions. Sixteen scenarios with four different cases were developed within WIN scenarios for converting to renewable energy. Based on WIN scenarios, from WIN1 to WIN16 indicates that the energy demands and emission values were continuously decreasing as the factor to focus on more renewable energy sources such as wind. To analyze the growth in energy demand and reduction in emission values by considering different percentages of wind values, CASE A (WIN1-WIN4) depicts that the energy demand is 286.2 TWh, and associated CO_2 emissions are 66.9 MMT. Similarly, for CASE B (WIN5-WIN8), the value of energy demand is 267.6 TWh, and the associated emissions are

62.6 MMT. In CASE C (WIN9-WIN12), energy demand decreases and reaches 252 TWh, and the associated emissions are 59.0 MMT. The values of energy demand and CO_2 emissions for CASE D (WIN13-WIN16) are 236.5 TWh and 55.3 MMT, respectively. The results in Figure 4a,b show the highest value of energy demand for WIN1, while the lowest emissions are for the WIN16 scenario with the highest percentage of wind. The same transition for energy demand and CO_2 emission is noted in the WIN scenario as in the SOL scenario. This highlights that wind energy could be extracted from wind to also generate clean, sustainable, and cheap electricity.
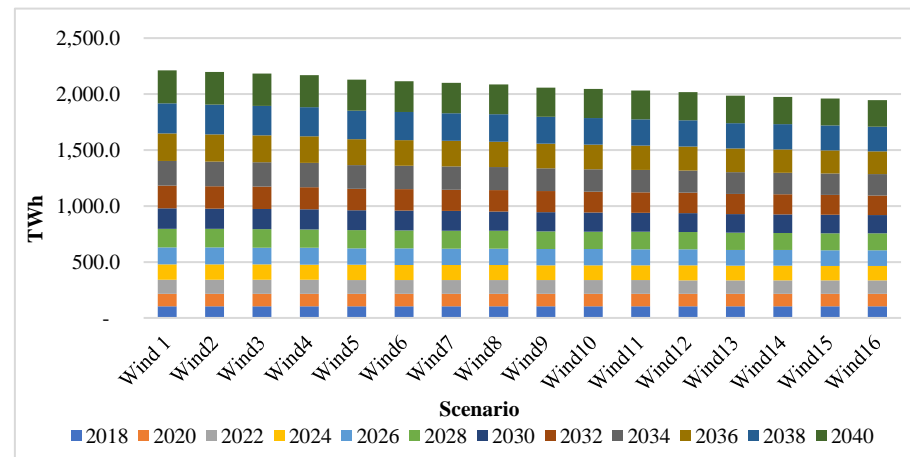

(**a**)

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Figure 4. (**a**) Energy demand of WIN1 scenario–WIN16 scenario. (**b**) Emissions of WIN1 scenario–WIN16 scenario.

3.2.3. BIO Scenarios

The BIO scenarios built under the RE scenarios were developed to investigate the energy demand and CO_2 emissions. Sixteen scenarios with four different cases were developed within BIO scenarios for converting to renewable energy. Based on BIO scenarios, from BIO1 to BIO16 indicates that the energy demands and emission values were continuously decreasing as the factor to focus on more is cleaner energy sources such as biomass. To analyze the growth in energy demand and reduction in emission values by considering the different percentages of biomass values, CASE A (BIO1-BIO4) depicts that the energy demand is 298.9 TWh, and associated CO_2 emissions are 68.6. Similarly, for CASE B (BIO5-BIO8), the energy demand is 275.3 TWh, and the associated emissions are 64.9 MMT. In CASE C (BIO9-BIO12), energy demand decreases and reaches 260.8 TWh, and the associated CO_2 emissions are 62.8 MMT. The growth of energy demand and values

of CO_2 emissions for CASE D (BIO13-BIO16) are 248.2 TWh and 60.0 MMT, respectively. The results in Figure 5a,b show the highest value of energy demand for BIO1, while the lowest emissions are for the BIO16 scenario with the highest percentage of biomass. The biomass scenario could also be used on a larger scale in forecasting years particularly after 2034, with the same trend noted for the solar and wind scenarios. Biomass energy could gain attraction due to its ability to produce clean and sustainable energy for everyone.
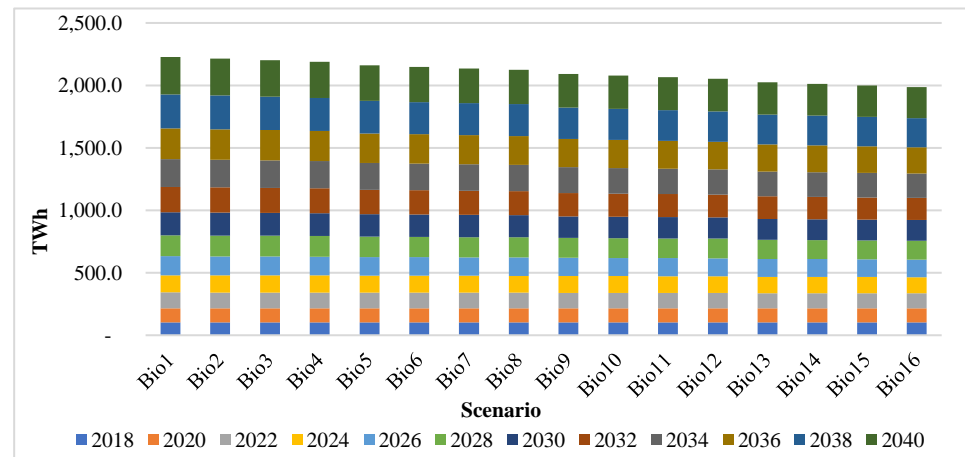
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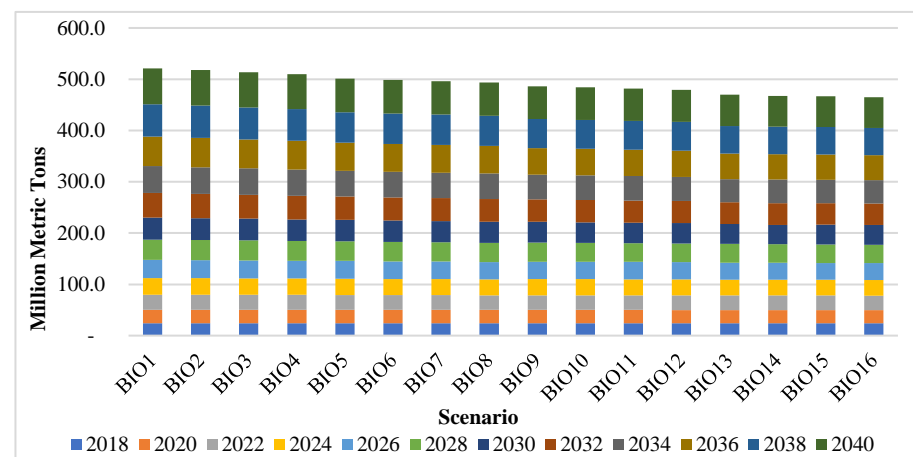
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Figure 5. (**a**): Energy demand of BIO1 scenario–BIO16 scenario. (**b**) Emissions of BIO1–BIO16 scenario.

3.3. HYD Scenario

Hydro is an appropriate source for energy production with low carbon emissions. The chairman of the WAPDA stated that the Diamer-Basha dam has a capacity for water storage of 8.1 million acres (MAF) and a capacity of 4500 MW and described to the ICCI delegation the hydropower projects which are under construction at the Dasu, Keyal Khawar and Khurram Tangi dams. These dams are crucial projects for the water, food, and energy protection of Pakistan and will go a long way to economic stabilization. These dams will generate cheap energy that will improve the productivity of Pakistan in industry and agriculture.

3.4. NUC Scenario

Nuclear energy is a stable and low carbon source but incredibly costly. No direct emissions of carbon dioxide are produced from nuclear power plants. Contrary to the use of fossil fuels, nuclear reactors do not create air or carbon dioxide emissions during

operation. Nuclear energy produces almost the same emissions as wind and solar, but it requires more energy to operate the nuclear power plants. According to the IAEA country nuclear power profiles, the country currently has five nuclear operating plants with a combined production of 1430 MW, while 2200 MW is under construction.
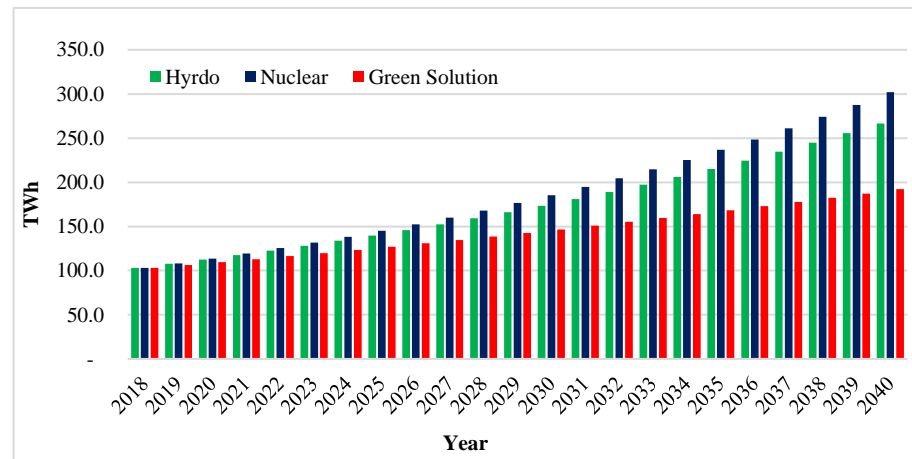
3.5. Green Solution Scenario

Pakistan has committed to the international community in its intended nationally determined contributions (INDC) that the country will reduce its 2040 projected emissions by 20–25%. Renewable energy has less CO_2 emissions than fossil fuels. Apart from maintenance and construction, renewable energy resources such as solar and wind do not emit any CO_2 emissions. Compared to fossil fuels, renewable energy production is cleaner, easier to maintain over time, quicker, and even cheaper than fossil fuels. Uddin et al. [56] conducted a detailed study with regards to a renewable energy perspective in Pakistan and reported that Pakistan has 62.1%, 25.8%, 8.2%, and 3.9% share of energy for fossil fuels, hydropower, nuclear power, and renewable energy, respectively. The use of renewable sources (solar, wind, biomass), hydro, and nuclear give a green solution for the Pakistan power policy. Although green energy solution sources have their drawbacks, these resources must be exploited to a great extent for cleaner energy production. Wind energy has drawbacks such as noise production, variation of wind speed throughout the year with consequently inconsistent output power, land restrictions, unstable nature prediction, etc. Moreover, wind energy is difficult to install at off-grid sites. It is reported in studies that 62% of people of Pakistan are residing in rural areas which highlight the importance of biomass energy production [56]. One biomass energy limitation is that a large number of crops would be needed to produce biomass energy which is not a suitable option because the agricultural market balance could be disturbed, leading to an increment in food prices [57]. A research study [58] reported that food security has become worse due to the production of biofuels. Solar energy has almost negligible drawbacks compared to wind and biomass energy. Pakistan is located in a sunny region of the world and can benefit from solar energy for all applications. Solar energy in Pakistan can be generated throughout approximately all of the country to fulfill energy demands in summer for cooling and winter for heating purposes.

Based on a green solution scenario, the energy demand and associated CO_2 emissions values are continuously decreasing if the comparison of all the three scenarios is considered as shown in Figure 6a,b. To analyze the energy demand growth and associated CO_2 emission values, the green solution scenario depicts that energy demand and emission values are 192.1 TWh and 37.7 MMT, respectively, which are somewhat lower than the scenarios of nuclear and hydro. The energy demand for the scenario of nuclear energy is observed as 302.2 TWh which is higher than the three scenarios (green solution, hydro, and BAU). The green energy solution presented in this study is a more effective solution than the nuclear energy sector. The energy demand and emissions for the hydro scenario are observed as 266.7 TWh and 48.7 MMT, respectively, which is greater than the scenario of the green solution. Overall, the results show that the green solution is the most suitable and appropriate scenario as it has lower energy demand and associated emissions of CO_2. The total energy supplies were 8.4% higher than the previous year; 86 million tons for the period 2017–2018. The energy utilization by source in FY2018 is 31.2, 34.6, 8.7, 1.2, 12.7, 7.7, 2.7, 1.1, and 0.1% for oil, gas, LNG Import, LPG, coal, hydroelectricity, nuclear electricity, renewable electricity, and imported electricity, respectively. The projection to represent the utilization of power mix until 2040 as aligned with the estimates of the book "the Energy Year" and the projection of the National Transmission and Dispatch Company (NTDC) can be shown by the forecast.

The utilization of three renewable and clean energy sources (biomass, solar, and wind) is observed as 3081 MW for the year 2018 and is expected to reach 33,598 MW by the year 2040. The details are shown in Figure 7. The evaluation of emission reduction occurred based on the recommended guidelines by INDC (intended nationally determined contribution) and the IEA (International Energy Agency). Overall, it is recommended that

the green energy scenario can meet the renewable energy targets of the country. Pakistan is a developing country so the usage of nuclear energy for electricity production is still beyond hope. Solar energy is the most suitable and viable option, more than wind and biomass (among the green energy solution sources) because of its wide availability in the country and almost zero hazards.

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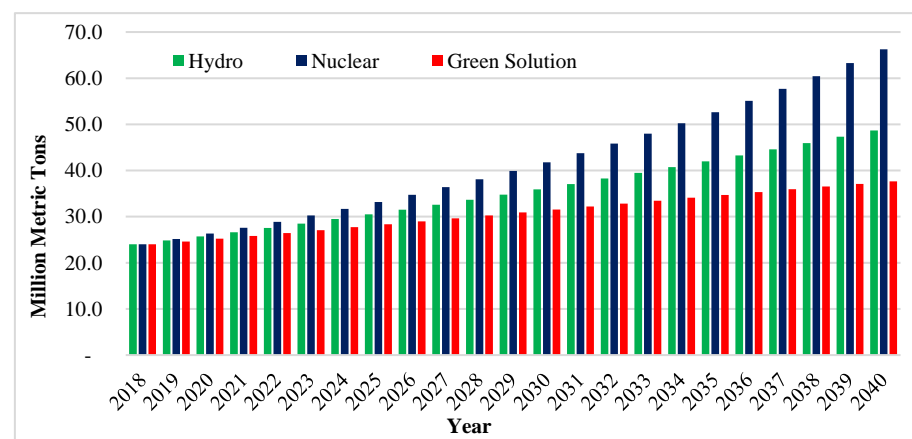
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Figure 6. (**a**) Energy demand of HYD, NUC, and GR solution scenarios. (**b**) Emissions of HYD, NUC, and GR solution scenarios.
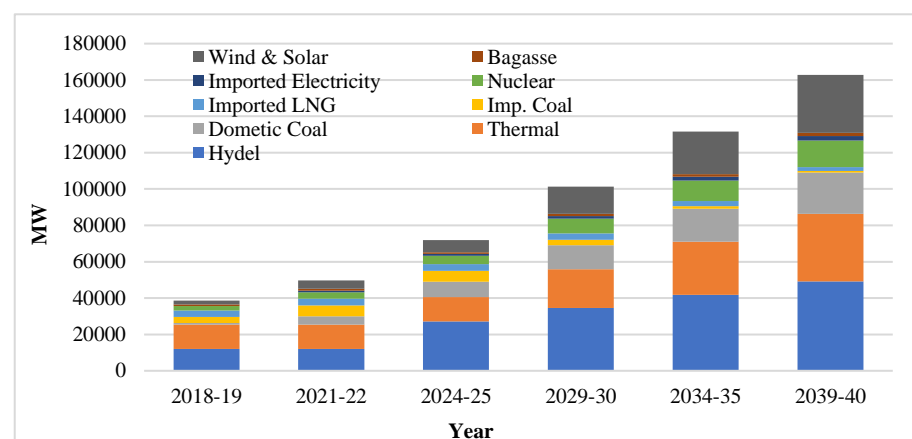

Figure 7. Projection of Pakistan energy utilization 2040.

4. Conclusions

There are various technologies for increasing the share of renewable energy in the Pakistan energy system. The study offers a realistic transformation plan, taking into account all renewable energy resources to achieve a renewable energy system. Energy supply stability can be accomplished by expanding supply in line with the development of the economic sector, which is based on optimism, such as investment-friendly energy policies, technological advancement, resource consumption commercially, and international supply agreements. This is a particularly beneficial approach for developing countries such as Pakistan.

The largest constraint to making this transformation is not related to energy grid prices but to renewable energy resource supplies that will be stretched to their limits. The highest value of energy demand is noted for the 1st scenario (WIN1, SOL1, and BIO1), while the lowest emissions are noted for the 16th scenario for each renewable source (WIN16, SOL16, and BIO16) with the highest percentages of wind, solar and biomass, respectively. The energy demand and emissions values shown by the green solution (hydro) are 192.1 TWh (266.7 TWh) and 37.7 MMT (48.7 MMT), respectively. The energy demand for nuclear energy is noted as 302.2 TWh and is higher than the green solution, hydro, and BAU. The green solution scenario with the lowest energy demand of 192.1 TWh relies on renewable technologies and has minimum emissions and externality costs making it the most suitable option in the future. Other described scenarios under RE show energy demand and carbon emissions values slightly below the defined value of BAU. However, the nuclear scenario has the highest energy demand values, even more than the BAU. Overall, the results show that the green solution is the most suitable and appropriate scenario because it has lower energy demand and associated emissions of CO_2 compared to other scenarios. Pakistan is a developing country so installing nuclear projects is the only hope for the country. Solar energy is the most viable option among the presented green energy solution sources for the country because of its huge potential, ease of use for on-grid and off-grid solutions, and no limitations.

Some of these possibilities are extremely unpredictable and involve the additional development of technologies and improvement in infrastructure to be attainable in the future. Despite these obstacles, the findings show that the Pakistan energy system can be converted into a renewable energy system with sustainable domestic resources while applying the same conditions as the green solution scenario. Key measures to promote energy conversion in all fields should be implemented.

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