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National energy scenario of Pakistan – Current status, future alternatives, and institutional infrastructure: An overview

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ABSTRACT

In this article, the current energy consumption of Pakistan is presented and the issue of security of electrical energy supply is discussed. The power sector has been looked from variety of aspects such as, demand and supply gap, diminishing energy sources, energy security, and increasing energy costs. Furthermore, the status of energy and potential of renewable sources of energy has been discussed as sustainable alternative. In addition, the roles of different sectors in the promotion and development of renewable energy technologies have been discussed. The renewable energy future prospects are encouraging in Pakistan with a total renewable energy potential of about 167.7 GW which is more than enough to meet the total electricity demand of the country. This vast potential of renewable sources of energy could be utilized to overcome the energy shortage which has not been utilized properly due to lack of policies and infrastructure. The diversification of existing energy resources and exploration of new sources is an important aspect to be considered in order to have a sustainable power development and its implementation in the country.

1. Introduction

Energy consumption is an index of industrial economy and prosperity of the people in a country because energy is an important factor for almost all human activities and developments. Due to increasing global population and materialistic lifestyles of the people, the energy resources are depleting rapidly. Furthermore, the increasing consumption of energy across the globe has adverse effect and implication on the environment and ecosystem of the earth. The usage of fossil fuels for energy generation is the major causes of environmental degradation. The increasing consumption and demand for energy shows that energy will be one of the major future problems of the world [1]. Alternative, clean and renewable resources of energy are required to meet this demand and at the same time to combat the adverse environmental problems. Renewable energy sources such as solar and wind have the potential to fulfill the energy gaps without emitting the greenhouse gases and affecting the ecosystem.

Pakistan is facing a severe energy deficiency and most of the northern areas are still not connected with the grid. Energy supply and demand gap is large and is widening with time. The country has limited fossil fuel resources and need to import to fill this gap [2,3]. Due to this energy shortfall, urban areas are facing 10–12 h load shedding while in rural areas electricity remains unavailable for 16–18 h [4]. To overcome the energy shortfall in the country it is necessary to diversify the energy resources like hydropower, solar, biogas and wind.

Pakistan is situated in the high solar isolation area on the Earth [5]. The potential of solar energy resources can be used to generate electricity in off-grid areas in the western deserts and northern regions. Additionally, solar energy can also be used in some other applications such as solar cookers, solar water heaters, etc. [6].

The solar power system is considered expensive while comparing with a power system operating on a conventional energy source. These comparisons often do not give a clear and true picture of cost analysis because the cost of a single unit of photovoltaic is compared with the power available at the doorstep of the house. The solar systems will be much more cost effective while comparing fixed and running cost of some mega solar projects in the national policy.

Globally renewable energies such as: solar, wind, and biomass can meet the rapid demand of the consumer and it can fulfill the increasing power shortages of Pakistan. The purpose of the present work is to evaluate the facts behind the current energy shortages in the country and potential of renewable energy as a viable alternative to overcome the gap between supply and demand. The recent developments on alternative energy technologies and their applications in the country to overcome the energy shortage problem have been discussed. In

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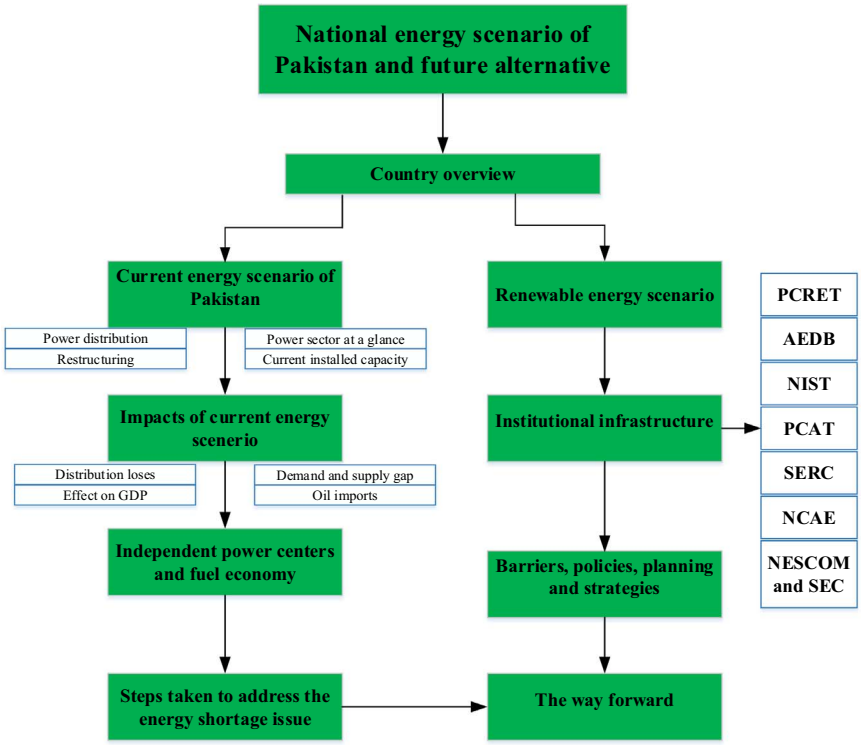


Fig. 1. Flow diagram of the article.

addition, this study also describes the role of the research and development (R & D) organizations and institutions in the country related to the promotion of renewable energy technologies.

The present research paper has been divided into different sections. The scope of the present work and need of alternative energy resources are introduced in Introduction Section 1 while Section 2 presents an overview of the country for better understating of available resources. Section 3, provides technical details about the current energy scenario of the country with respect to power sector, increasing energy cost, and new capacity addition plan. The effects of power shortfall on fuel economy and GDP have been discussed in Section 4 and different steps taken to overcome the energy shortage problem are presented in Section 5. The potential of renewable energy resources from variety of aspects has been discussed in Section 6. Role of different institutions and organizations working in Pakistan for the promotion of renewable energy is described in Section 7. Sections 8 and 9 discuss barriers and suggestions to overcome these hurdles for the development of alternative energy resources. Finally, a summary is presented in Section 10 for quick understanding. A graphical representation of the structure of article flow is presented in Fig. 1.

2. Country overview

Geographically, Pakistan enjoys an interesting strategic location. The country lies between latitudes 24° and 27°N and longitudes 61° and 76°E. It is comprised of five provinces namely Khyber Pukhtoon kha (KPK), Punjab, Baluchistan, Sind and Gilgit Baltistan. On the east border of the country is India, on the west is Iran, China is in the north, Afghanistan in the northwest and the Arabian Sea in the south. The total area of Pakistan including Federally Administered Tribal and Northern Areas (FATA and FANA) is about is 8,03,950 km^2, Mirza et al. [7]. Pakistan has about 1,046 km long coastline which is extending from Indian border in the east to the Iranian border in the west, NIO [8].

Pakistan is blessed with numerous natural resources including one of the world's highest mountain range, flow of fresh water, fertile lands, deep sea ports and rich reserves of natural gas, copper, coal and iron ores. Moreover, enormous potential of renewable energy sources is found across the country. The country inherited one of the world's best irrigation networks which have helped improve agriculture productivity and achieve associated gains in terms of poverty reduction in rural areas.

Unfortunately, limited work has been done in the past to explore naturally existing renewable energy sources. The effective utilization of existing or locally developed renewable energy technologies can play a vital role to meet the current energy deficit of the country.

3. Current energy scenario of Pakistan

The energy consumption per capita is an index to measure the prosperity of any society. An overview of the energy scenario indicates that Pakistan is an energy deficient country. The power sector growth, energy sources, cost of energy, etc. issues are discussed in details in the forthcoming subsections.

3.1. Power sector at a glance

In energy infrastructure a strong and complex relationship exists among different segments of the network from production to consumption. Lack of compatibilities between infrastructure and institutions has resulted in severe failure of functioning of the technical systems. Power sector infrastructure in Pakistan has passed through several stages since independence in 1947. The production capacity has increased significantly but not relative to the shooting demand in residential, industrial, commercial and agriculture sectors. Transmission and distribution sectors lagged behind equally.

The power sector of Pakistan is mainly under direct or indirect control of either government departments or private organizations. The energy infrastructure of the country is poorly managed, insufficient, inefficient, and under-developed. The major energy consuming sectors include domestic, industrial, agricultural, transport, commercial and government. The increase in energy consumption rate in domestic

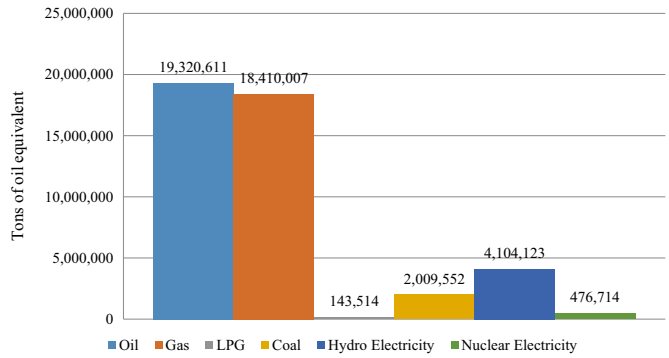


Fig. 2. Power sector in Pakistan [9].

sector is the highest (approximately 9%) followed by commercial (2.8%), industrial (3.8%) and transport (4.8%). However, there has been a decrease in the energy consumption in agriculture and government sectors by 7.1% and 1.4%, respectively. The primary energy sources are oil, gas, LPG, coal, hydro and nuclear [9]. The main energy resources used for power production are presented in Fig. 2, [9]. It is evident that gas and oil are the dominant sources of energy in the country.

3.2. Current installed capacity

The current power installed capacity is about 17,000 MW, peak demand is 22,000 MW and the average shortfall is around 5,000 MW. Electricity demand is growing at a rate of 10% annually while the capacity addition is increasing at 7% only. This shows that by 2030, the power requirement will be greater than 45,000 MW in the country. In the year 2000–2001, the national energy consumption was 25.26 million TOE which was 0.11% less than the previous year.

During the period from late 1990s to 2004–2005, the country had an extraordinary period with abundant electricity availability. The current energy shortage started in 2006–2007 with gradual widening gap between the demand and supply of electricity. Since then this gap has worsened and has reached a stage which is considered to be the worst of all such power crises in the history of the nation. At many instances during the year 2011, the electric power deficit had surpassed the level of about 5,000 MW. At one stage in the month of May 2011 the shortfall in electricity crossed 7,000 MW [10]. During the year 2012, net primary energy supply was 64,727 thousand TOEs as compared to 64,522 thousand TOEs in 2011, i.e. a growth of 0.32%. However, the growth rate of net primary energy supply on an average remained 1.8% for the last six years. On the other hand the growth rate of final energy usage remained 2.9% on an average for last six years.

3.3. Power distribution

Pakistan's power grid at distribution level (i.e., 132 kV) and below is being managed by two integrated public sector power utilities and nine Distribution Companies (DISCOs) administratively controlled by Pakistan Electric Power Company (PEPCO) and Karachi Electric Supply Corporation (KESC). DISCOs is responsible to supply the power on the national level to whole country except the metropolitan city of Karachi, which is supplied by KESC [11]. The system of DISCOs and KESC are interconnected through 220 kV double circuit transmission lines [12]. The transmission grid all over the country except the Karachi Metropolitan city is being managed by National Transmission and Dispatch Company (NTDC), a federal entity.

The national electricity mix includes hydro (28.4%), thermal (67.82%) and the rest (3.78%) [13]. The available data from the respective government departments indicated that current total installed capacity is 23,644 MW. The suppressed electricity demand in the country is 19,735 MW during summer and 14,922 MW during winter season.

3.4. Restructuring and new capacity addition plan

Countries around the world are in various stages of reforming and restructuring their power systems to better meet development needs and decarburization commitments. Changes in technology, business models, societal needs, and environmental goals are increasing pressure on countries to consider improvements to their electricity systems. The national economic conditions of Pakistan are greatly hampered at different levels due to the increasing cost of energy. The rising prices of fuel and electricity have become a serious concern for the people [14]. The rapid increase in fuel prices directly affects the other living expenses which make the living difficult and unaffordable for a large portion of the population.

The energy crises have become crucial because of its sole dependence on hydal and fossil fuel power generation. Currently, three major hydal power plants (Terbela, Mangla, and Ghazi Brotha) are generating electricity but their capacity is much lower than the growing needs of the electricity in the country. In view of current energy scenario, it is necessary to concentrate on means and ways to utilize renewable sources of energy like solar thermal, solar photovoltaic, wind, geothermal, and biomass. Of these sources of energy generation, solar and wind are fully developed technically and commercially accepted by the society and hence the power utilities and government should try to tap these sources for sustainable development.

WAPDA was restructured in 2007 to deal with inefficiencies and overcome the energy shortfalls in the country. After the restructuring, the generation of electricity has been given to four companies (GENCOs) and the distribution to ten companies (DISCOs). The transmission lines of 220 kV and 500 kV and grid stations owned by the WAPDA are being managed by the National Transmission and Dispatch Company (NTDC). WAPDA still controls the thermal and hydropower power generation in the country while Pakistan electric power company (PEPCO) is managing the transition of WAPDA to corporate structure and promoting independent power producers (IPPs). To fulfill the energy demands of the country, WAPDA has an ambitious plan (Vision 2025) to expand its generation capacity in three phases and develop 23 hydro-power projects in different water borne locations. The power generation contribution (installed and available) by different power generation identities is shown in Fig. 3 [15].

Private power and infrastructure board (PPIB) was established in 1994 after the expansion of the ministry of water and power. Independent power producers (IPPs) were introduced under the provision of this new power policy to invest and enhance the generation capacity and in 2002 incentives were offered to the IPPs, Siddiqui [16]. A major drawback of this policy is that most of the IPPs power plants use the furnace oil and a limited number of plants are operated on natural gas which results in increased cost of generation and pollution. Under the provision of Regulation of Generation, Transmission and Distribution of Electric Power Act 1997, the National Electric Power

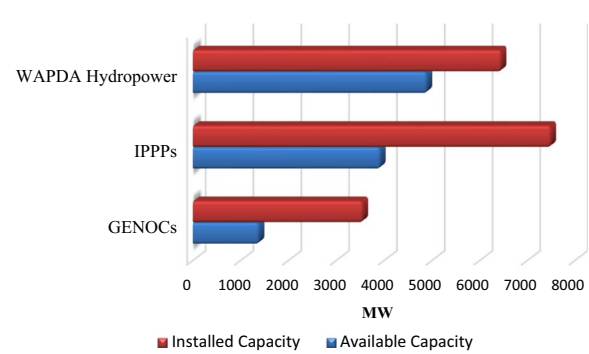


Fig. 3. Power generation by various sectors [15].

Table 1
Electricity supply projections 2009–2030 (PEPCO & KESC (Combined system)).

Year	Total generation (MW)	Addition (MW)	Year	Total generation (MW)	Addition (MW)
2008–09	19951	2354	**2019–20**	**63000**	**5475**
2009–10	22205	2354	2020–21	68475	5355
2010–11	24559	3854	2021–22	73830	5130
2011–12	28413	3132	2022–23	78960	5960
2012–13	31545	3382	2023–24	84920	5730
2013–14	**34927**	**4434**	2024–25	90650	7550
2014–15	39361	5360	2025–26	98200	6780
2015–16	44721	3999	2026–27	104980	6890
2016–17	48720	3450	2027–28	111870	8410
2017–18	52170	4815	2028–29	120280	7210
2018–19	58985	6015	2029–30	127490	9640

Source: PEPCO, P & D Div.

Regulatory Authority (NEPRA) was established. This regulatory authority is responsible for issuing the licenses to the IPPs for power generation and monitoring the performance standards of transmission and distribution of electric power. It also determines and controls the tariff rates of electric power generation and distribution in the country.

As shown in Table 1 the installed capacity in 2013–14 should have been 34,927 MW, whereas the actual current installed capacity is 23,823 MW that indicates a shortage of 11,104 MW. The planned installed capacity for 2019–20 is expected to be 63,000 MW which requires installation and commissioning of 39,177 MW more by 2020, Yousuf et al. [17].

4. Impacts of current energy scenario

The present energy scenario of Pakistan is the worst in the history of the nation and has been marred by unprecedented load shedding and a massive circular debt. Pakistan spends around 60% of its total foreign exchange on the import of fossil fuels, Khan and Pervaiz [18]. High oil prices have forced the nation to curtail the quantity of oil being imported in the country and as a result demand supply gap of electricity has increased. The cumulative national power installed capacity has drifted from a surplus of 1,230 MW in 2005 to a shortage of 5,885 MW by the end of year 2010, Farooq and Kumar [19]. Although fossil fuels produce useful energy but are also responsible for the production of harmful greenhouse gases and hence need to be addressed by making use of clean and renewable sources of energy. The estimated potential of solar power in Pakistan is around 2,900 GW, [20] and the annual solar irradiance in the country is around 1900–2200 KWh/m^2, Asif [21].

4.1. Energy supply and demand

The gap between energy supply and demand in the country is increasing rapidly. Like other developing countries, Pakistan is also facing major energy deficiency due to fast increase in population and dependence on primary energy sources. Due to rapid urbanization, the consumer base of electricity has increased at a fast rate. Growth of 85% in the electricity consumers is observed during last 15 years. In 2050, the energy demand is estimated to increase by three-fold while the increase in supply is not so encouraging. The reserves of gas and oil are depleting at a fast rate and are left only for 10 and 19 years, respectively. The local coal reserves which are available in abundance have not been properly utilized in the matrix of energy supply in the country. The electricity deficiency in the country is increasing which is negatively affecting the economic growth. The evidences suggests that in coming years this deficiency will grow more rapidly until and unless concrete constructive and meaningful measures are taken to use alternative sources of energy for power generation in the country.

4.2. Transmission and distribution losses

High transmission and distribution losses, the frequent disruption of grid power supply, financial constraints and difficulties to extend the grid to inaccessible remote areas are the main hurdles for the rural electrification. Off grid electrification, which has proven to be viable both economically and technically, can be a good option for the electricity supply for remote areas where grid connection is not available. The solar and wind energy options can be excellent off grid alternatives in those areas where there is no electric grid [22]. The problem in the power sector may be attributed to the fact that this sector is being controlled by different entities which have their own policies and procedures and are not governed by the central controlling body. These major power centers are:

- Ministry of water and power and 19 subsidiary agencies.
- Energy wing of ministry of planning and development.
- Ministry of petroleum and natural resources and 16 subsidiary agencies.

Three more ministries and seven other agencies are also involved in energy sector which further complicate the energy scenario in Pakistan.

4.3. Oil imports

Oil accounted for 32.0% of the primary energy supply and 29.0% of final energy consumption of the nation during 2010–2011. Crude oil reserves available in different oil fields as on June 30, 2011 were about 306.6 million barrels out of the proven reserves of 944.3 million barrels. Twelve different companies are involved in crude oil production from around 133 oil fields developed so far in the four provinces. Oil & Gas Development Company (OGDC) has the highest share of about 55.9% in crude oil production during 2010–2011, followed by BP Pakistan Exploration & Production Inc. and MOL Group having a share of about 12.7% and 11.4% respectively. About 68.1% of total crude oil requirements were met through imports during 2010–2011. The country's expense on crude oil imports during this period was stood at USD4.69 billion. Fig. 4 provides the details related to the imports of the crude oil in the country over the past ten years between 2001 and 2011, Nayyar et al. [23]. There are seven petroleum product refineries in the country with a total refining capacity of about 13.2 million tons per year of refined petroleum products. In addition, the country imports a substantial amount of refined petroleum products. The imports related to petroleum products were to the order of 12.5 MTOE during 2010–2011. Fig. 5 provide details with respect to imports of refined petroleum products in the country during the period of 2001–2011, Nayyar et al. [23].

4.4. Overall effect on gross domestic product (GDP)

Gross domestic product (GDP) is a monetary measure of the market

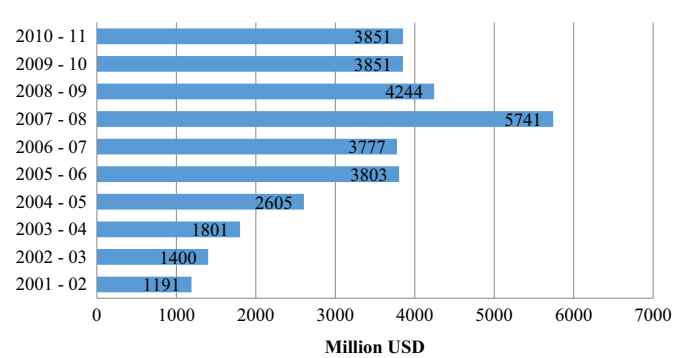


Fig. 4. Expenses on the import of crude oil during 2001–2011 [23].

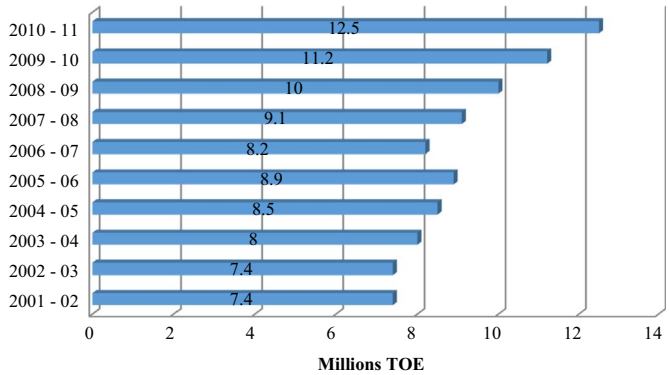


Fig. 5. Import of petroleum products during 2001–2011 [23].

value of all final goods and services produced in a period (quarterly or yearly). Nominal GDP estimates are commonly used to determine the economic performance of a whole country or region, and to make international comparisons. The relationship between the annual growth rate of GDP and energy consumption is presented Fig. 6 [24]. During past few years, the national economic growth has been hampered by these energy outages as can be seen from Fig. 3. Currently, serious efforts have to be made to install new generation capacities to maintain the economic growth and meet the rising demand of energy.

The shortages in energy have cost the country up to 4% loss in GDP over the past few years. This has led to the shutdown of many industries and factories (including more than five hundred alone in the industrial hub city of Faisalabad), paralyzing production and increasing unemployment. Additionally, such situations also imperil the much-required investments in development and infrastructure [25]. There has been a resultant increase in power generation costs coupled with the high proportion of line losses.

Overall, the performance of the power sector was poor or below expectations during this period. It was not the only slow growth in new capacity addition but also the up gradation of the existing unit was not addressed properly. The share of power in the public sector development programs fell to less than 3% of the GDP in this decade.

5. Steps taken to address the energy shortage issue

To address the electricity shortage problem, development of new power plants and construction of dams must be planned and executed. In this regard, the private sector has added the new capacity of 1,602 MW which included 852 MW capacity based on natural gas during the years 2008–2012. To run the gas based power plants, a total of 1,571 mmcfd of natural gas is required. On the other hand the imports of crude oil, necessary to run the oil based power plants, also hindered due to the fact that the circular debt receivables reached to unsustainable levels. Due to the above reason, the fuel required for thermal generation of the power, was reduced to 30% of the daily requirement, [26].

Table 2 summarizes the energy consumption in different sectors. Domestic and Agriculture users cumulatively utilize 60% of the total energy produced [6]. Demand from these two sectors is season dependent and increases during summer time. The government of Punjab is working seriously on solar energy to resolve the load shedding issue up to maximum level as shown in Table 3 [27]. In this regard, energy department of Punjab has established Quid-e-Azam solar power company (QA Solar) to develop large scale power projects in the province of Punjab which is providing 100 MW. China power investment crop (CPI Group) has shown keen interest in four power projects of 660 MW and 300 MW to be installed in Lahore and Bahawalpur, respectively. A summary of key energy sectors are presented in Fig. 7 [28].

Table 2
Energy consumption in various sectors (%) [6].

Sector	Punjab	Sindh	KPK	AJK	Baluchistan	Grand total
Agriculture	6.8	1.2	0.5	0.0	4.1	13.0
Bulk supply	3.5	1.7	0.7	0.0	0.1	5.9
Domestic	28.0	9.3	7.3	0.8	0.6	46.1
Industry	18.3	6.1	1.9	0.1	0.2	26.7
Commercial	4.7	2.0	0.7	0.1	0.1	7.5
Other	0.3	0.3	0.0	0.1	0.0	0.7
Total	61.7	20.6	11.1	1.1	5.5	–

Table 3
Installed unit and their capacities [27].

Installed	Units	Total capacity
Micro-hydel	538	7.8 MW
Wind turbine	155	161 kW
Solar PV	300	100 kW
Biogas plant	4,000	1,800 m^3/day
Solar dryer	21	5,230 kg/day fruit

6. Renewable energy scenario of Pakistan

The energy obtained from natural resources such as solar, wind, geothermal, and biomass is known as renewable energy. Since the beginning of civilization, these resources of energy have been important for human beings and are capable of providing energy with almost zero emissions of greenhouse gases and are available everywhere irrespective of geographical and political boundaries. These resources are abundant in nature and enough to fulfill the energy demands of entire world, Asif [23]. Therefore steps needs to be taken to explore, develop, and establish sustainable and secure energy sources on national level to combat the energy supply and demand gap. The use of these renewable resources can secure long term sustainable energy supplies and also reduce harmful emissions. The promotion and utilization of renewable sources of energy will create new employment opportunities, new industries for the manufacturing of photovoltaic panels, wind turbines components, and also the tourism as a result of solar and wind farms development.

The electricity shortfall can be overcome to certain extent by using potential of solar and wind energy in the country. In 2011, utility scale ground mounted solar PV plant with 1 MW installed capacity was initiated [29].

Fig. 8 shows the technical potential of different renewable energy

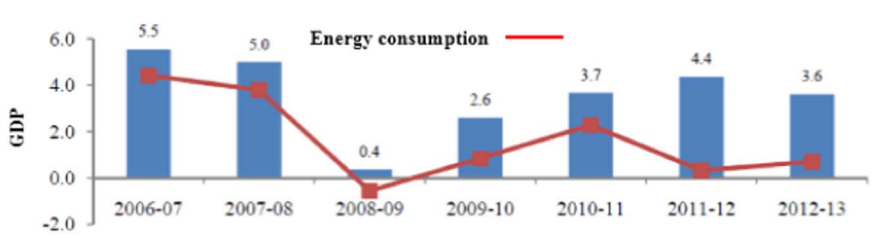


Fig. 6. Relation between growth rate of GDP and energy consumption [24].

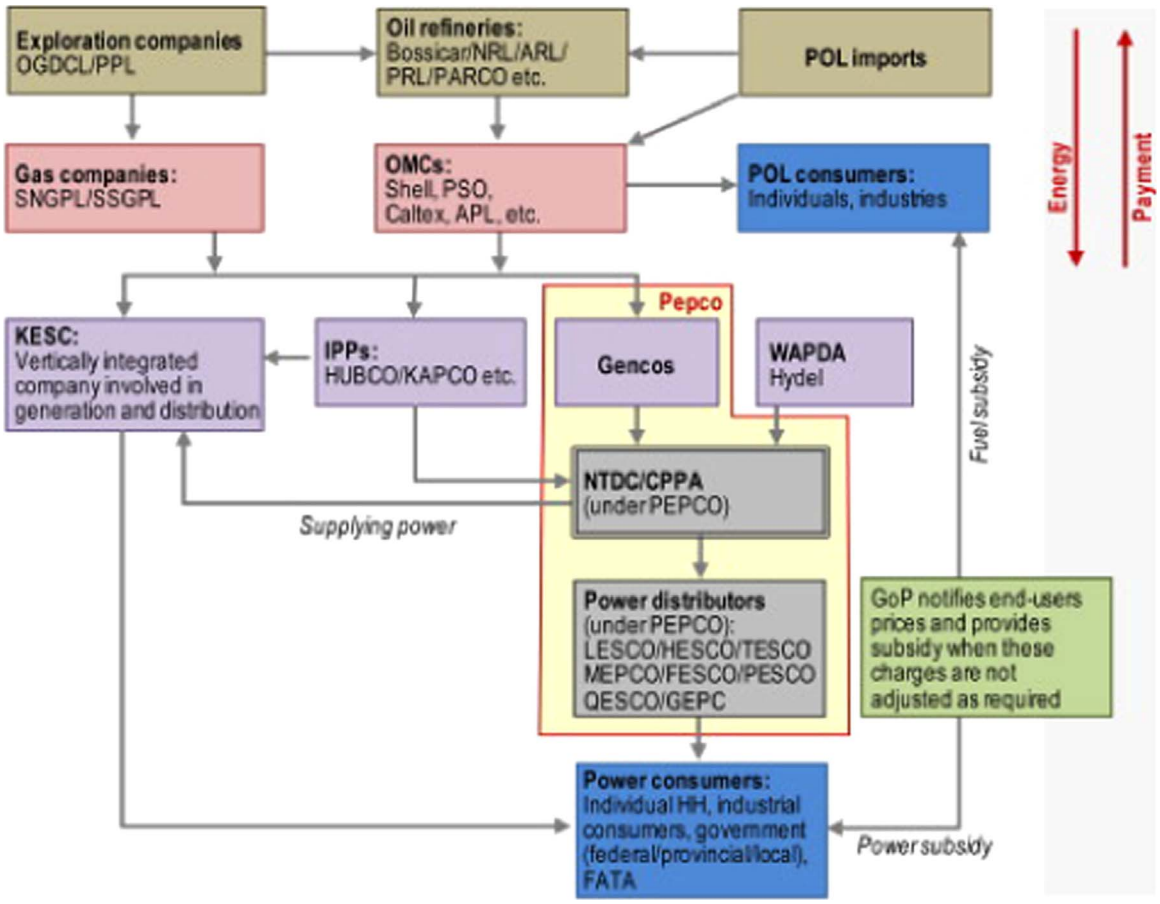
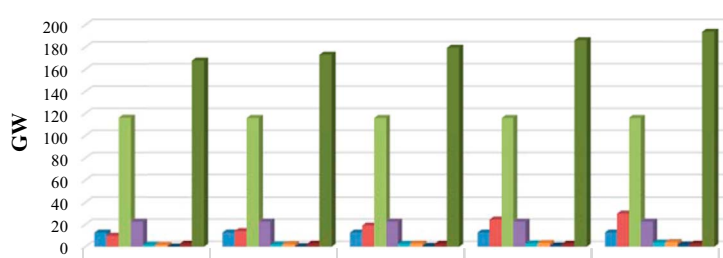


Fig. 7. Key sectors of the energy mix in Pakistan [28].

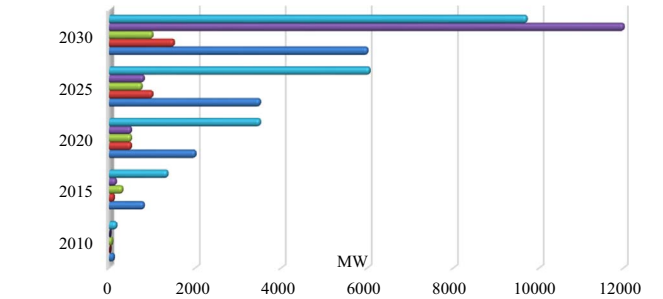
sources in Pakistan [4]. The total renewable energy potential in Pakistan is about 167.7 GW which is 8 times more than the total electricity demand of 21 GW of the country. The government issued a white paper in 2005 to meet 10% of total electricity demand from renewable sources by 2012 [30]. However, till 2008 no grid connected renewable energy based capacity was added to the existing energy network. The government revised the renewable energy target in 2008 and set a new target of 5% of total installed capacity from renewables by 2030 [31]. Fig. 9 provide and insight in to the details of renewable energy installation plan set by the government [29]. A number of financial and fiscal incentives have been offered to the investors in order to materialize this plan. One of the major financial incentives included the permission for power generation companies to issue corporate registered bonds and shares. The fiscal incentives included the tax exemption on income, machinery, and equipment.

Therefore, it is the sole responsibility of the Government to initiate mega projects to explore the naturally existing wind energy potential in the coastal areas of Sindh and Baluchistan. The wind energy should be used in the localities of the coastal areas of Sindh and Baluchistan to avoid energy transmission losses.



	2010	2020	2030	2040	2050
Wind (grid connected)	12.8	12.8	12.8	12.8	12.8
Solar PV (DCNT)	9.9	14.1	19.1	24.5	29.9
Solar PV (CNT)	116.2	116.2	116.2	116.2	116.2
Solar thermal (CNT)	22.6	22.6	22.6	22.6	22.6
Biomass (field residues)	1.7	2	2.5	3	3.7
Biomass (animal waste)	1.6	2.3	2.8	3.4	4.1
Biomass (MSW)	0.2	0.4	0.7	1.1	1.9
Small Hydro	2.7	2.7	2.7	2.7	2.7
Total	167.7	173	179.3	186.1	193.9

Fig. 8. The estimated potential of different renewable energy sources for electricity production in Pakistan, 2010–2050 [4].



	2010	2015	2020	2025	2030
Total	162	1350	3500	6050	9700
Small hydro	1	150	500	800	12000
Biomass	60	300	500	750	1000
Solar	1	100	500	1000	1500
Wind	100	800	2000	3500	6000

Fig. 9. Government plan for promotion and utilization of renewable energy sources in the power sector of Pakistan [29].

6.1. Renewable energy projects

The details of some major renewable energy based power plants to be commissioned till 2015 –2016 are given in Table 4 [4]. As seen from the data given in Table 4, progress has been made in case of small hydro and wind power capacity additions but despite enormous potential of solar energy there is a lack in the deployment of solar based electricity generation projects. A comparison of two major sources of renewable energy such as solar PV and wind is made with gasoline operated power plants in Table 5 [18].

7. Institutional infrastructure

The organizations involved in the research and development of solar in Pakistan are described in following subsections.

7.1. Pakistan Council for Renewable Energy Technologies (PCRET)

The Pakistan Council for Renewable Energy Technologies (PCRET) was established in 2001 with a major objective of research and developments in the field of renewable technologies in Pakistan [27]. PCRET coordinates research activities in the areas of solar thermal, solar PV, micro-hydel, biogas, and wind energy [7]. These research outcomes are of immense use for domestic and industrial applications [32]. The aim of PCRET include to develop and deploy clean, carbon free, and environment friendly sources of energy which combat the health hazards and dependence on primary energy sources. Some of the developments related to solar energy technology carried out by PCRET to benefit the society include the distribution of 90,000 efficient cook stoves, 100 solar cookers and 100 solar dryers; installation 300 pv systems of 200 – 500 W rated power; installation of 130 wind turbines to supply power to 430 house, and production unit for the manufacturing of PV panels [33]. Other R & D initiatives and developments of PCRET include the following:

- Solar PV and thermal products testing laboratory.
- Community size solar dryers.
- Solar electrification of remote area in the country.
- Organic solar cells.
- Low power solar lights.
- Renewable energy training centers.

PCRET has developed solar cells, silicon wafers, PV systems, such as solar torch, home light systems, street lights, solar fountain, solar mobile charger, etc. A number of locally designed, developed, and manufactured devices are being used for different applications across the country as shown in Fig. 10. Solar PV systems developed by PCRET are being used for electrification in rural and remote areas of the country [34]. Some of the target by PCRET for the promotion and development of solar energy up to 2020 are listed in Table 6 [35].

Table 4
The details of available potential of different renewable resources in the country and expected installed potential till 2016 [4].

Energy source	Total potential (2010)	Capacity addition	Total installed capacity	Remaining potential
Wind	12,764	900	900	11,864
Solar PV (decentralized)	9,893	0	0	9,893
Solar PV (centralized)	116,197	1	1	116,196
Solar thermal	22,587	0	0	22,587
Biomass	5,420	24	24	5,396
Small hydro	2,658	166	312	2346
Total	169,519	1091	1237	168282

Table 5
Comparison of energy sources [18].

	Solar panel (1 kVA)	Gasoline generator (1 kVA)	Wind turbine (1 kVA)
Capital cost	Rs. 65,000	Rs. 110,00	Rs. 120,000
Fuel consumption	Nil	RS. 114/h	Nil
Life span	25 years	4–5 years	10–15 years
Maintenance	Nil	Rs. 6.5/h	Rs. 3.5/h
Carbon monoxide	Nil	6.5 g/Liter	Nil
Un-burned hydro-carbon	Nil	0.72 g/Liter	Nil
Nitrogen oxides	Nil	58 g/Liter	Nil

7.2. Alternative Energy Development Board (AEDB)

The Alternative Energy Development Board (AEDB) was established in 2003 by the Government of Pakistan as the central national body related to renewable energy. The facilitation, promotion, and development of alternative energy technologies are the main objectives of this organization. The main target of AEDB was to achieve a share of 10% from renewable technologies in the energy mix of the country by the year 2015 [36]. AEDB has different international donor organizations such as GEF, ADB, USAID, UNDP, and GTZ for collection of funds to promote, execute and implement different alternative and renewable energy projects in the country. AEDB is a member of the Board of Directors of the International Solar Energy Society (ISES). Some of the initiatives and developments carried out by AEDB include electrification of some 800 villages through renewable sources of energy, establishment of solar thermal power plant, framing of policies and incentives for the promotion of renewable sources of energy in the country.

AEDB is also playing its part in abatement of Greenhouse gases and improving the Environment of the country by promoting environment friendly Renewable Energy projects. The efforts of AEDB for the promotion, execution and implementation of Alternative Renewable Energy Projects were recognized internationally as well when AEDB was made the coopted member of the Board of Directors of the World Wind Energy Association (WWEA) and the International Solar Energy Society (ISES) presented the chair of the Pakistan Section to AEDB.

7.3. National Institute of Silicon Technology (NIST)

National Institute of Silicon Technology was established in 1981 for

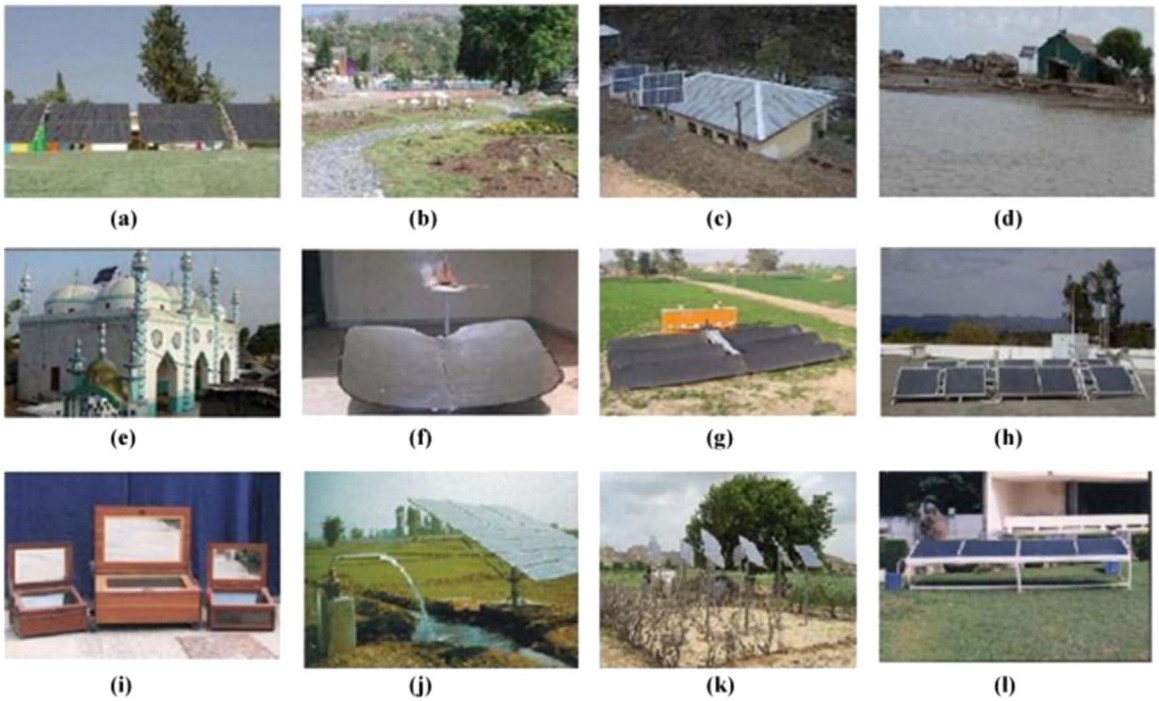


Fig. 10. Applications of PCRET developed solar systems [34]: (a) solar power (b) solar garden lights (c) solar school lighting system (d) solar powered system for a mosque (e) solar powered system at a mosque in Thar area. (f) parabolic type solar cooker (g) solar dryer (h) solar water heater (i) solar box type cooker (j) solar tube well (k) solar panels being used for water extraction (l) solar still.

Table 6
Target of PCRET for promotion and development of solar energy (2016–2020) [35].

Type	Present status	Target 2016–20
Solar water heaters manufacturing through private sector with PCRET technical services	Designed and developed 05 different models of SWH for commercialization	25,000 units 125–260 l/day
Solar dryers manufacturing through private sector with PCRET technical services	Designed and developed 03 different models of 20,100 and 500 kg capacities	100,000 units
Solar cooker manufacturing through private sector with PCRET technical services	Designed and developed box and dish type solar cookers for commercialization	200,000 units
PV modules production manufacturing through private sector with PCRET technical services	Developed solar cell production capacities up to pilot scale	20 MW

Source: http://www.cret.gov.pk/files/about_us.html.

research and development and awareness program of solar energy in the country. The main focus of the research by NIST is on the development of mono crystalline silicon based solar cell technologies. Some of the solar assisted systems developed by NIST are solar street lights, solar lanterns, solar battery chargers, solar home systems, solar cookers, solar water heaters, solar dryers, solar desalination plants etc.

7.4. Pakistan Council of Appropriate Technology (PCAT)

For the promotion and development of alternative and appropriate technology in the country, Pakistan Council of Appropriate Technology (PCAT) was established in Islamabad in 1975. The major PCAT research was involved pertaining to energy, food, habitation, and health through water desalination, solar cookers, etc. [37].

7.5. Solar Energy Research Centre (SERC)

The Solar Energy Research Centre (SERC) works under the supervision of the Ministry of Science and Technology [38]. The main objectives of research and development program of Solar Energy Research Centre are to explore different methodologies for utilization of solar energy potential in the country. Solar thermal power generation, solar desalination, and solar air conditioning are the main applications developed by this organization.

7.6. National Commission for Alternative Energy (NCAE)

The Government established NCAE for the development and promotion of various renewable technologies [39,40].

7.7. NESCOM and SEC

For the development of solar energy technologies, National Engineering and Science Commission (NESCOM) and Solar Energy Centre (SEC) were established. In 1980s,, SEC designed and developed solar flat plate water heating system. A water desalination plant with a total capacity of 500 gallon per day was also installed by SEC near Gwader for purification of drinking water.

7.8. Other R & D organizations

Some of the organizations involved in R & D of solar and other renewable energy sources have been discussed in detail in the previous sections. Other than that a number of universities and private organizations have remained actively busy in R & D work related to renewable energy sources. A summary of all R & D organizations in Pakistan is provided in Fig. 11. These organizations have developed and promoted renewable energy products but most of them remained at modest level and were unable to go on large-scale production. Different organizations are playing their role for the promotion of solar energy based systems in the country. These companies are selling

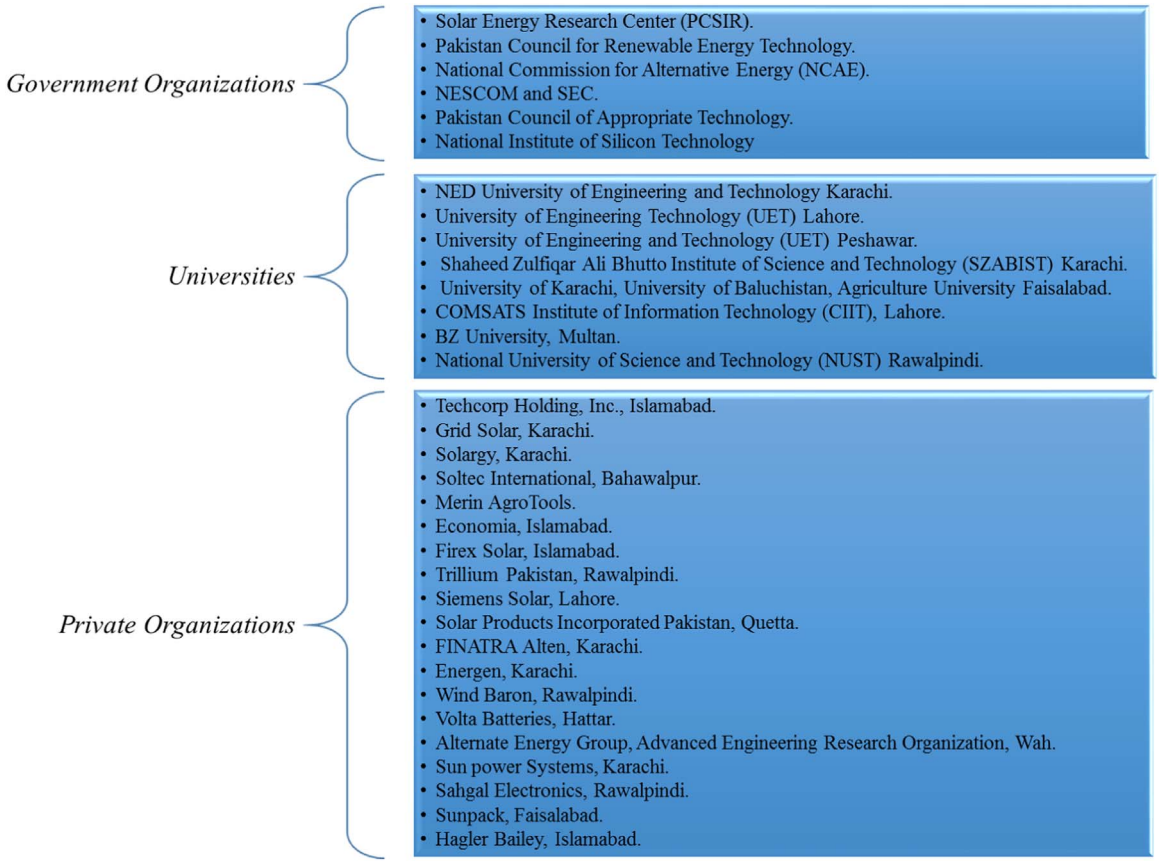


Fig. 11. R & D organizations in Pakistan.

batteries, PV modules, regulators, invertors, as well as practical low power gadgets for load shedding including PV lamps, solar geysers, battery chargers, and garden lights, etc. [41].

8. Barriers, policies, planning and strategies

The initial investment cost, institutional weaknesses, management irregularities, and lack of appropriate government policies are some of the major barriers for development of solar energy in the country. Fig. 12 presents a list of other existing barriers for the development of solar energy technologies. A policy framework is required for the promotion of solar technologies for domestic and commercial applications in order to achieve its long term environmental and socio-economic benefits. Recently, the government has realized the importance of solar energy to improve the socio-economic conditions and to control the environmental pollution. Some of the recommended measures needs to be taken for the development of renewable technology are [59]:

- The inclusion of solar energy technologies in the long term national energy policy.
- The provision of sufficient resources to develop lab scale models to commercial level.
- The provision of incentives to motivate entrepreneurs to come forward and invest in the deployment of renewable sources of energy [42] and [43].
- The provision of subsidies and loans to the end users.
- The provision of field demonstration, education and proper training of the people.
- The installation of solar lights and other appliances at public places such as parks, streets, and schools [44].
- The allocation of sufficient funds from the national budget to the renewable energy institutions.
- The promotion of the usage of solar energy technologies during public activities such illumination of stadiums using PV systems during major sport activities.

Many things need to be considered in order to achieve sustainable development in any area of human endeavor. A summary of different challenges and essential factors for sustainable development of solar energy sources include public awareness, research and development, infrastructure development, commercialization, decentralized power delivery system, market development, education and outreach programs, government participation and subsidies, technology transfer and adoption, monitoring, and evaluation of all the initiatives and their timely outcome.

Electricity generation cost from renewable sources can be cut down by various initiatives from the government. Local production of PV cells can result in a substantial reduction of cost of PV technology which will decrease the cost of generated electricity. The main constraints in the diffusion of PV technology are unawareness of local communities, unavailability of technical information and poor renewable energy policies.

PV technology is more suitable for remote areas and small power applications such as for Baluchistan, Sindh and the Thar Desert. Baluchistan which has largest area as compared to other provinces in Pakistan has very small population density (21persons/km^2). In these areas PV technology is the only and best suited option to provide electricity to the inhabitants. Individual units can be installed for each house to fulfill the small energy requirements of about 50–100 W per house. The northern and western part of Pakistan, Hindu Kush-Himalayas (HKH) region is blessed with plenty of solar radiations (about 4–6 kWh/m^2) and sun shine hours. In 1980s,, different agencies installed seven solar stations for village lighting in various parts of

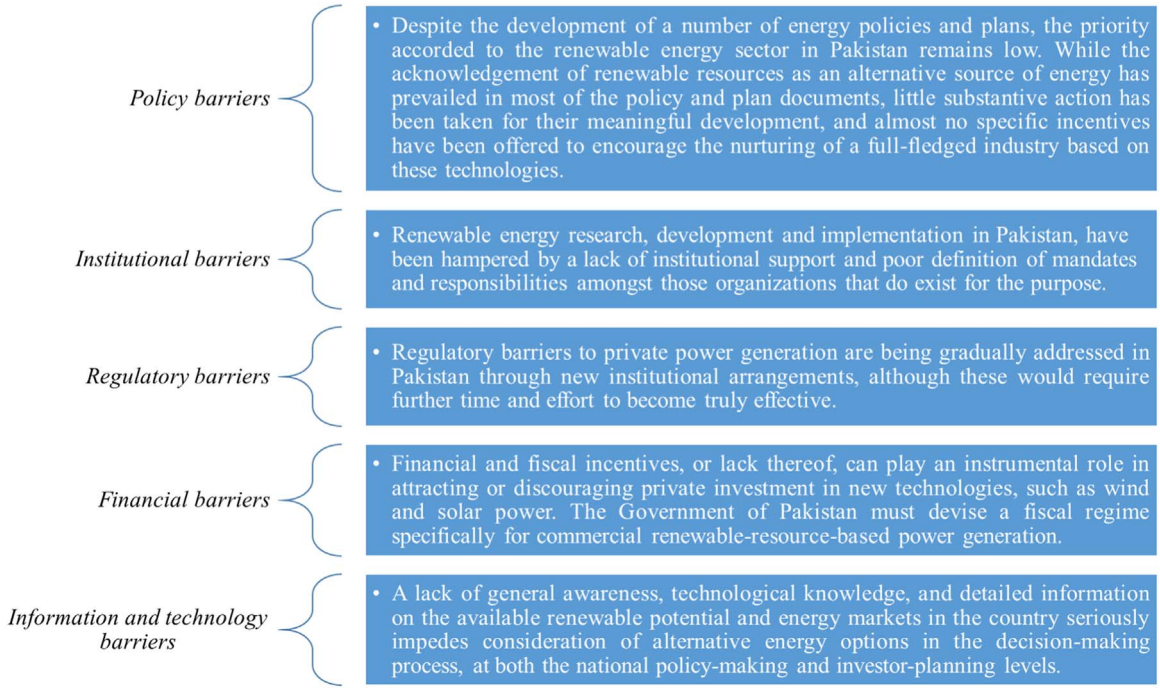


Fig. 12. Existing barriers to solar energy development in Pakistan.

HKH region. The total capacity of these systems was about 234 kW.

Efforts have been made for the local fabrication of PV cells and small scale installation of PV systems in Pakistan. The local fabrication ability exists only at Pakistan Council of Renewable Energy Technology (PCRET) but is still limited to pilot scale. Siemens Pakistan is actively involved in PV business in Pakistan for more than 10 years. They have installed complete solar systems for house electrification, water pumping, telecommunication, highway communication, navigation, oil and gas fields and street lighting.

9. The way forward

In the light of this study, some important constraints have been addressed for widespread utilization of solar energy in particular and renewable technologies in general. It has been found that technological awareness of solar systems is limited in the country. Accordingly, it has been proposed that the universities should take lead in offering introductory and advance courses about planning and development of these systems which could cater the energy needs of the country. As an example, Lahore University of Management Sciences (LUMS) and School of Science and Engineering has offered Renewable Energy Systems course to introduce the basic of PV technology and other solar based technologies to the students. The other major universities in Pakistan should also offer such courses to develop and implement solar technologies in the country.

The increasing population, materialistic lifestyles, and industrialization putting pressure on power utilities to provide more energy which is a true global phenomenon and is valid too for Pakistan. The major power production in the country is based on fossil fuels and a shortfall in the import of it causes direct reduction in the power generation and which then adversely affects all spheres of human activities. Hence is very timely that Pakistan should strive hard to supplement its energy mix through new, clean and renewable sources of energy. The solar energy potential in the country is far more than the total electricity demand and hence to be tapped properly and intelligently. According to revised white paper, the government has set a target of 5% energy deployment through renewable sources till 2030. The proper utilization of solar energy resources can help to build a sustainable energy infrastructure, enhance energy security, and decrease dependence on imported fossil fuels.

10. Conclusions

Pakistan is a developing country of Asia and its increasing population and industrialization resulted drastic increase in energy consumption. The country's energy sector heavily depends on fossil fuels in terms of primary as well as secondary energy sources. The country's power infrastructure needs to be modified and reorganized. This situation indicates that current indigenous energy sources cannot meet the increasing energy demands and the solution of this problem lies in the energy conservation, energy efficiency and utilization of renewable energy sources. Various forms of renewable energy sources are being utilized in the developed countries to reduce their dependence on fossil fuels and cease greenhouse gas emissions.

Furthermore, the importance of energy supply and demand is significant not only for the economic prosperity but also for the current and future generations. Pakistan is suffering from the worst energy scenario now days and many parts of the country are yet not connected to the grid. Electricity demand is growing at a rate of 10% annually while the power generation capacity is increasing only by 7%. This shows that by 2030, the power requirement will be greater than 45,000 MW. Due to this energy shortfall in urban and rural areas electricity remains unavailable for 10–18 h. The major causes of energy crisis are dependence of energy sector on imported fossil fuels, mismanagement, irregularities, and inappropriate government policies.

Alternative energy sources must be developed in order to provide the energy to all sectors in the country and avoid or minimize the evil which usually take birth due to power cuts and its improper distribution. The national renewable energy potential is about 167.7 GW which is more than enough to meet the total electricity demand of the country. Some progress has been made in case of small hydro and wind power capacity additions. The proper utilization of this potential can significantly reduce the burden on the energy system and help in overcoming the load shedding problem and improving the economy of the country. The major reasons for energy shortfall and advantages of renewable energy usage are illustrated in Fig. 13.

Now the time and situation has reached to such a critical stage that

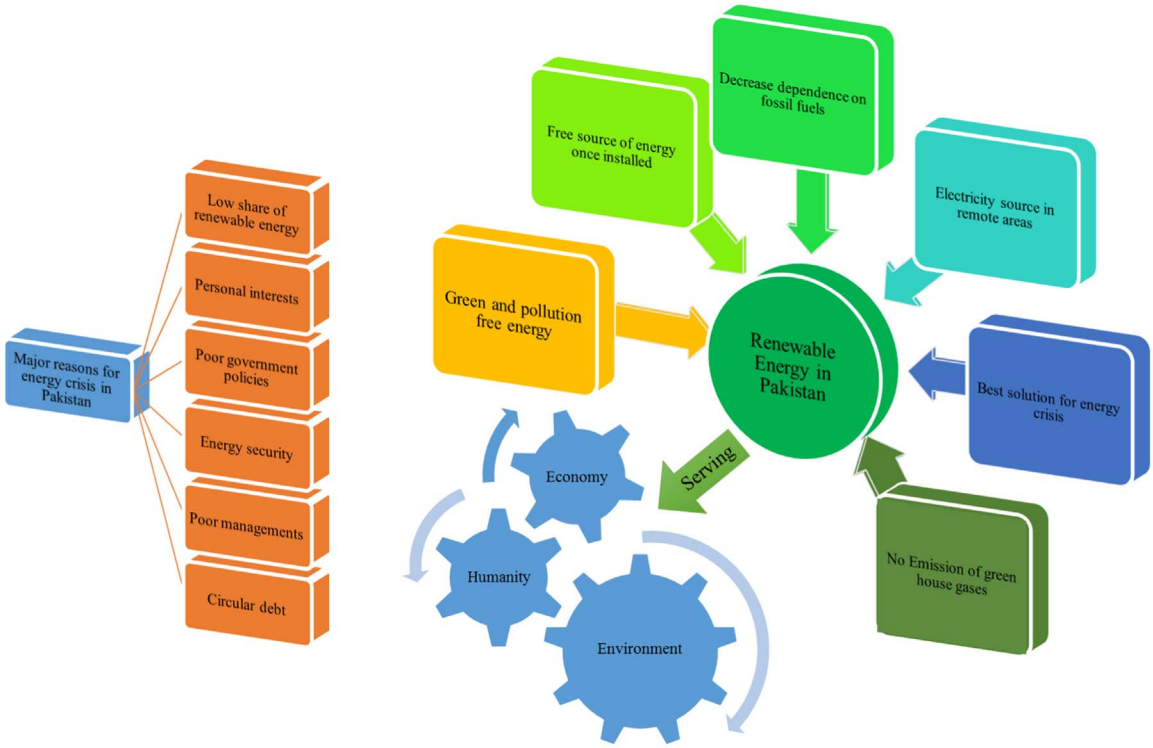


Fig. 13. The major reasons for energy crisis in Pakistan and advantages of renewable energy.

the government should set a renewable energy deployment target with time line and at the same time should provide a positive environment and easy to work policies to encourage private sector to invest on renewable energy development. The government should make firm policies on grid connectivity issues, land availability, feed in tariff, subsidies, tax benefit, loan incentives, and licensing. Last but not the least, honesty, political will, and cooperation of people from all walks of life is critically important for the sustainable development of renewable sources of energy and ultimately the safe life of the people.

Acknowledgements

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