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Diagnosis of electricity crisis and scope of wind power in Pakistan

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Electricity performs an integral role in the economic development and improvement in the living standard of a nation. Unfortunately, Pakistan is currently experiencing one of its worst periods of power shortages. The purpose of this paper is based on diagnosing the present electricity crisis in Pakistan and to discuss the outlook for the diffusion of wind power in the mix of established electricity generation, which relies too heavily on imported fossil fuels at the cost of precious foreign exchange. The existing electricity transmission and distribution (T&D) network has miserably failed to meet the country's requirements. Diversification of the present electricity-generation mix, with a significant increase in the contribution from exploitable wind-power potential recommended, along with upgrading and overhaul of existing power plants and the T&D infrastructure, reductions in non-technical losses and enhancing investment attractiveness (for both thermal and renewable) are some key measures likely to facilitate improved and affordable electricity supply and mitigate the current and forecasted long-term electricity supply–demand gap. Specific recommendations are presented towards overcoming identified challenges and obstacles to the harnessing of the country's abundant renewable energy resources, especially for wind power generation.

1. Introduction

Geographically, Pakistan is situated between latitudes 24° and 37°, longitudes 62° and 75°, bordering with India to the east, Iran to the west, China to the north and Afghanistan to the northwest (Figure 1). In the south, Pakistan has approximately 1100 km of coastline with the Arabian Sea and an exclusive economic zone extending up to 370 km in these hot waters. The total land area of Pakistan is 796 950 km^2, its population density is 260 inhabitants/km^2 (urban population of 40%) and the country has plenty of solar, wind and water resources. Per capita, electricity consumption for 2015–2016 was 457 kWh (Ahmed *et al.*, 2016), almost six times less than the typical average electricity consumption across the developed world (Mirza *et al.*, 2015).

In 2016, the total installed electricity-generation capacity in Pakistan was approximately 25·0 GW, against the peak demand of 26·4 GW (NTDC, 2017). For 2013–2017, the actual gap between peak electricity demand and total supply remained in the range 5–8 GW (Mengal *et al.*, 2014; NEPRA, 2017), which represents almost 50% of the country's dependable electricity-generation capacity (Shakeel *et al.*, 2016). Furthermore, the present electricity transmission and distribution (T&D) network in Pakistan is not capable of the efficient and reliable distribution of more than approximately 18 GW to the end users, with the outdated network worsening the supply–demand gap, such that the transmission of anything over this capacity for extended periods increases the likelihood of breakdowns in the distribution network (Ullah, 2013). At present, almost 25% of the total population in Pakistan has no access to electricity and those that have access are bound to live without electricity on a daily basis for more than 12–14 h in cities, with the situation often worse at typically 16–18 h in rural areas (Harijan *et al.*, 2011; Kessides, 2013).

The foremost causes of electricity shortages in Pakistan are closely connected with technical and policy reasons, including unsatisfactory performance of power production plants, the outdated T&D network and an inefficient energy mix (Latif and Ramzan, 2014; Shaikh *et al.*, 2015). According to Malik (2012) and Valasai *et al.* (2017), other factors include the underperformance of responsible administrative and regulatory bodies and corruption in the management of the limited capital resources of the power sector.

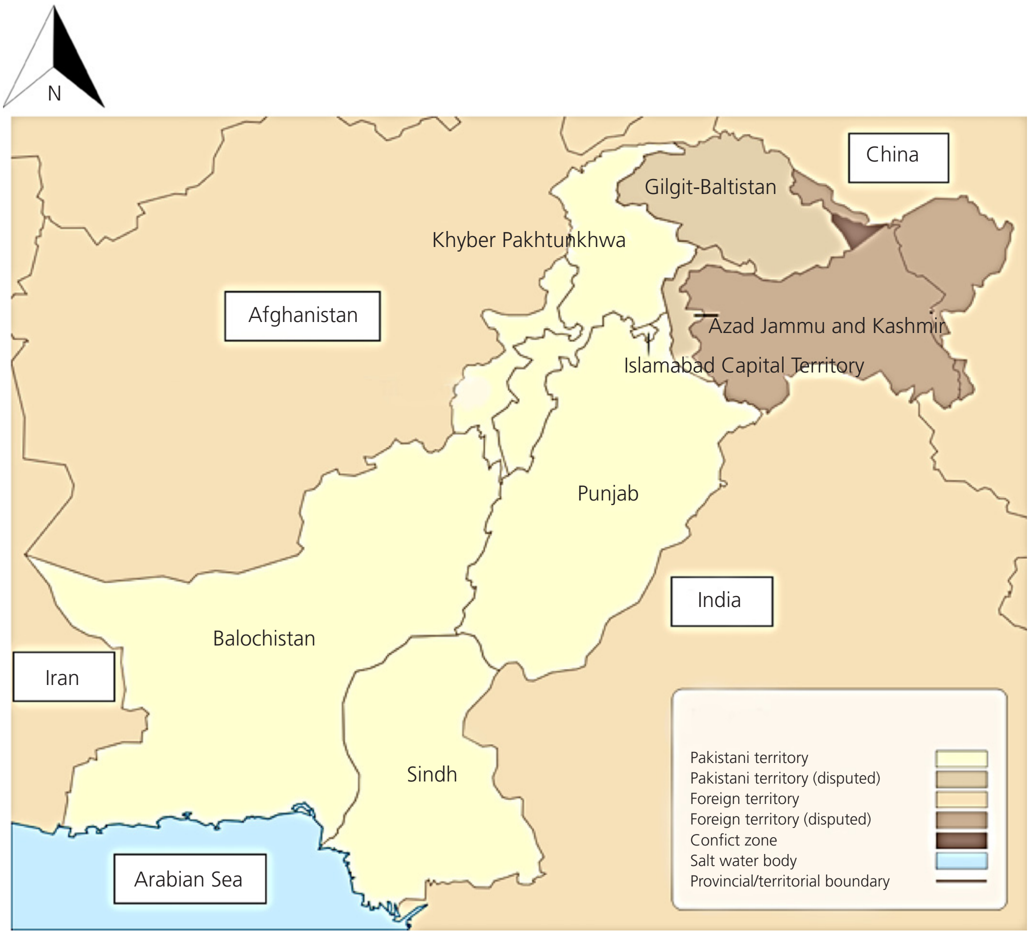

Figure 1. Neighbouring countries and administrative divisions of Pakistan (Mirza *et al.*, 2007)

Numerous studies have demonstrated that Pakistan possesses huge renewable energy (RE) potential, such as from wind (Bhutto *et al.*, 2013; Mengal *et al.*, 2014; Mirza *et al.*, 2010), solar (Bhutto *et al.*, 2012; Jabeen *et al.*, 2014; Khalil and Zaidi, 2014), biomass (Amjid *et al.*, 2011; Bhutto *et al.*, 2011) and geothermal (Abbas *et al.*, 2014) means. Among these, wind energy is relatively more promising for commercial harvesting. For instance, at the time of writing this paper, the share of wind power of the total electricity-generation capacity in Pakistan was only 0·9 GW (Baloch *et al.*, 2016), against its potential of approximately 320 GW, as documented by Mirza *et al.* (2015). According to Beck and Martinot (2004), Brown (2001) and Wüstenhagen *et al.* (2007), latent barriers to wind-power development include present policies, institutional hurdles, regulatory barriers, insufficient financial and fiscal incentives and often poor industrial and technological infrastructure.

Given the situation described, the purpose and focus of this paper is towards diagnosing the present electricity crisis in Pakistan and to discuss the outlook for the diffusion of wind power in the mix of the larger established electricity-generation technologies. Specific recommendations are presented towards overcoming identified challenges and obstacles to the harnessing of the country's RE resources, especially its wind power potential.

2. Electricity generation, supply and demand in Pakistan

2.1 Electric power sector entities

Power generation in Pakistan comprises of a mix of thermal, hydroelectric, nuclear and RE units. At present, a number of entities working under the umbrella of the Government of Pakistan (GoP) (as illustrated in Figure 2) are responsible for the planning, generation and T&D of electricity to the end users. Essentially, there are two vertically integrated bodies: (*i*) the Pakistan Electric Power Company (PEPCO), created in 2007 as bifurcation of the Water and Power Development

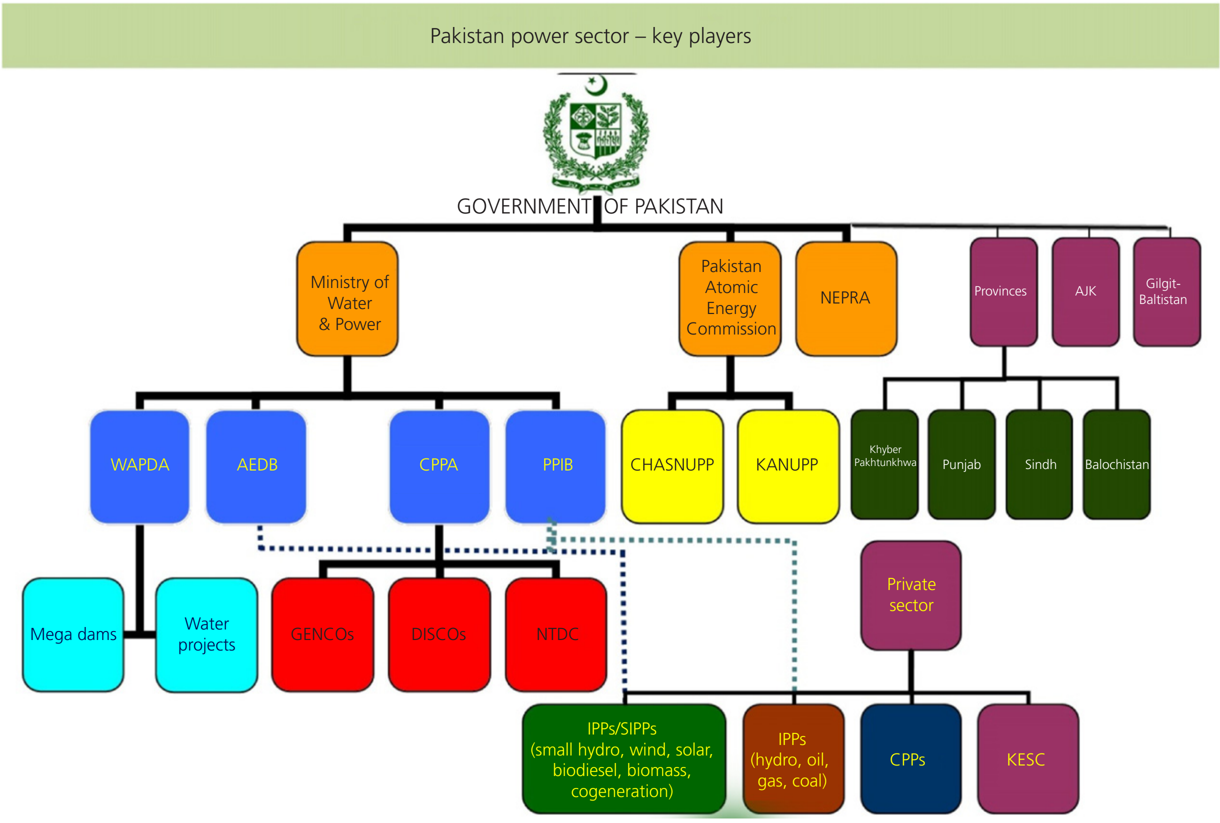

Figure 2. Organogram for power sector entities in Pakistan (adapted from Kessides, 2013; Perwez *et al.*, 2015; Qazi *et al.*, 2017)

Authority (WAPDA) and authorised to operate throughout Pakistan apart from Karachi city and surrounding areas; (*ii*) the Karachi Electric Supply Corporation (KESC), which functions in the private sector. In April 2012, with the worsening power crisis, the PEPCO's Board of Directors approved its dissolution, with its functions transferring to the National Transmission and Dispatch Company (NTDC) and later to the Central Power Purchasing Agency (CPPA) (Kessides, 2013; Valasai *et al.*, 2017). The functions of the National Electric Power Regulatory Authority (NEPRA) include the regulation of the electric power sector, encompassing the granting of licences, tariff determination and prescribing performance standards (Zakaria and Noureen, 2016).

Referring to Figure 2, WAPDA is responsible for giving a unified direction for the development of water projects and hydropower (Shaikh *et al.*, 2015). Before its dissolution, PEPCO was fully empowered and remains responsible for the management of ten corporatised distribution companies (DISCOs), four public sector electricity generation companies (GENCOs) and the NTDC (Baloch *et al.*, 2016). More than 30 independent power producers (IPPs) also significantly contribute to electricity generation in Pakistan and are regulated and systematised through CPPA and KESC. Further details on the roles and responsibilities of the different entities referred to above can be found in the work of Amjid *et al.* (2011), Mirza *et al.* (2008), Perwez *et al.* (2015), Shaikh *et al.* (2015) and Valasai *et al.* (2017).

2.2 Electricity supply and demand situation in Pakistan

As depicted in Figure 3, the total installed electricity-generation capacity was marginally higher than the peak electricity demand over the period 2010–2015. However, with the actual maximum generation capacity limited to 18·5 GW due to issues such as high petroleum prices, availability of indigenous energy sources, electricity T&D losses, sub-optimal power plant efficiency and circular debt, the shortfall between supply and demand during peak periods frequently reached up to 8 GW (Mengal *et al.*, 2014; NEPRA, 2017).

It is projected that without the required corrective measures, the supply–demand shortfall may reach up to 13 GW by the year 2020 (Kessides, 2013; Shaikh *et al.*, 2015). As illustrated in Figure 4, over the period of 2010–2016, approximately 67% of the installed electricity-generation capacity in Pakistan

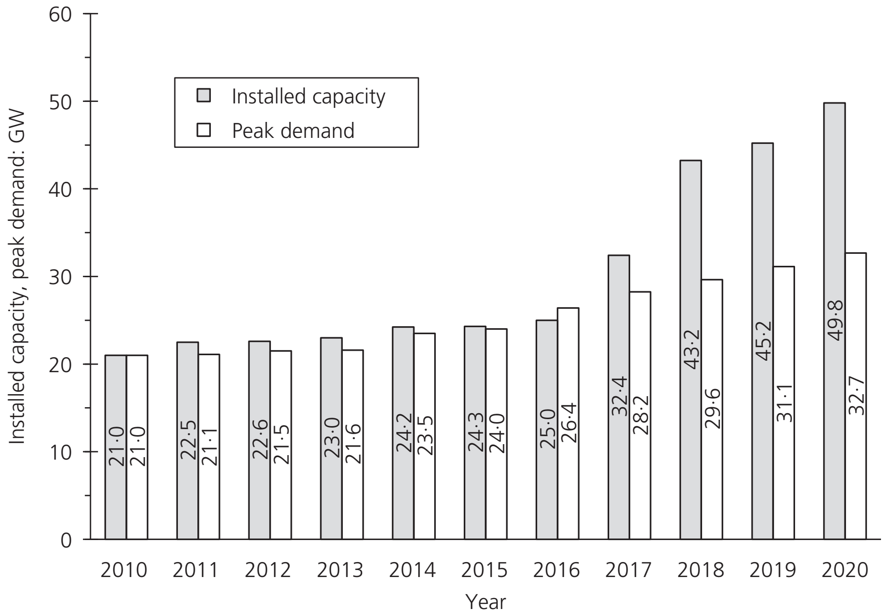

Figure 3. Recorded and projected installed capacity and peak demand of electricity in Pakistan (NEPRA, 2016; NTDC, 2017)

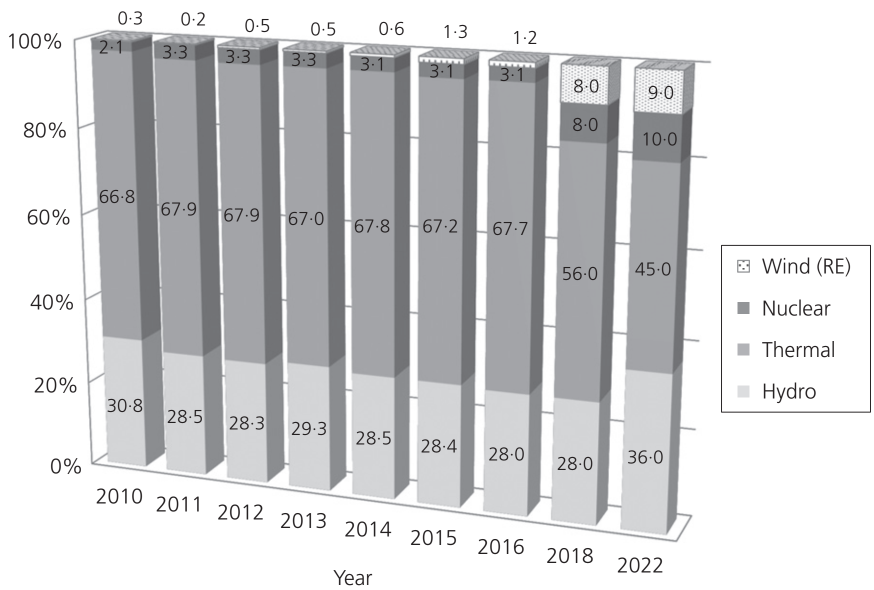

Figure 4. Electricity-generation sources in Pakistan. Note: 2010–2016 data are reported by NEPRA (2017) and NTDC (2017); 2018 and 2022 data are projections made by GIZ (2016)

was dependent on fossil fuels (liquefied natural gas, liquefied petroleum gas, furnace oil, natural gas), with approximately 29% from hydropower, 0·2–1·2% from wind power and approximately 3% from nuclear power plants (Ahmed *et al.*, 2016; NTDC, 2017; Perwez *et al.*, 2015).

Most IPPs within Pakistan depend on imported fossil fuels at the cost of massive foreign exchange, thereby creating adverse pressures on the poor economy of the country (Farooqui, 2014; Harijan *et al.*, 2011; SNC-Lavalin Inc., 2011). For instance, in the fiscal year 2016/2017, the oil import bill was almost 50%

(US$20 billion) of total imports, practically equating to the country's total exports revenue. Although Pakistan has huge coal reserves, estimated at 185 billion tonnes, they have not been utilised to their full potential on account of their often poor quality, non-existence of necessary infrastructure, location drawbacks, transportation problems (Uqaili *et al.*, 2003), lack of experience in advanced coal-combustion emissions control technologies and financial constraints. The scenario of nuclear power plants is promising in Pakistan, although high cost, technology barriers and international restrictions are the big hurdles. According to Harijan *et al.* (2011) and Uqaili *et al.* (2003, 2007), another reason is that Western countries are reluctant to collaborate with Pakistan regarding the expansion of nuclear power in the country.

Due to Pakistan's fast-growing economy and population, the expected swift industrialisation, electrification of villages, and increase in living standards, it is projected that electricity demand in the coming years will increase at the rate of 8–10% per annum (Javaid *et al.* (2011), cited by Shakeel *et al.* (2016)). As such, the country would require an installed electricity-generation capacity of 54 GW by 2020 and 113 GW by 2030 in order fully to meet its electricity requirements (Javaid *et al.*, 2011). The GoP power-generation plan up to 2030 predicts that electricity supply in Pakistan will increase at an average rate of 11% per annum, with 65% of the increase in installed capacity coming from thermal-based electricity generation (GoP, 2010). In other words, the current overdependence on fossil fuels for electricity generation is anticipated to continue. A study in the field of international co-operation for sustainable development by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) (see GIZ, 2016), however, forecasts a distinctly different scenario, projecting that by 2022, the electricity-generation contribution from thermal power plants in Pakistan could reduce to 45% of the total installed electricity-generation capacity, whereas the share from hydroelectric, nuclear and wind (or other RE resource) power plants could reach up to 36, 10 and 9%, respectively (see Figure 4).

2.3 Sector-wise consumption of electricity in Pakistan

Over the period of 2011–2016, the residential sector was the major consumer, accounting for almost 45% of all electricity produced in Pakistan, followed by the industrial (26·0%), agricultural (10·26%) and commercial (6·64%) sectors (NEPRA, 2017; Trimble *et al.*, 2011). Similar figure breakdowns have been reported by Mirza *et al.* (2015) and Perwez *et al.* (2015), and also for the period 2003–2004 by Perwez *et al.* (2015), with a similar trend expected to prevail up to 2030.

With improvements in living standards, it is expected that given present growth trends, the demand for electricity from the residential sector will strongly increase in the near future. Further, the overall number of electricity consumers has increased on account of the increase in gross domestic product (GDP), the rapid rate of urbanisation (standing at 2·77% per annum (CIA, 2017)) and the extension of the national grid to include additional rural areas; for instance, Kamran *et al.* (2015) reported a trend of approximately 7% per annum increase in electricity consumers. In other words, based on this growth rate, the number of electricity consumers will substantially increase from 24 million in 2017 to 35 million and 50 million by the end of 2027 and 2037, respectively (Kamran *et al.*, 2015), demonstrating the scope for future power-generation projects required in Pakistan. For the period 2005–2010, the average growth in electricity demand was 8% per annum, and is forcasted to continue at this rate to 2035 (NTDC, 2011), such that the total electricity demand could be up to 474 GW by 2050 (Kamran *et al.*, 2015).

2.4 Electricity T&D losses in Pakistan

Figure 5 illustrates the involvement of the different power sector entities in Pakistan responsible for the generation and (or) purchase of electricity for delivery to the end users. Figure 6 shows schematically the electricity network encompassing generation, transmission and finally distribution to the end users.

By the end of 2016, the total length of electricity transmission lines in Pakistan was greater than 50 000 km (NTDC, 2017).

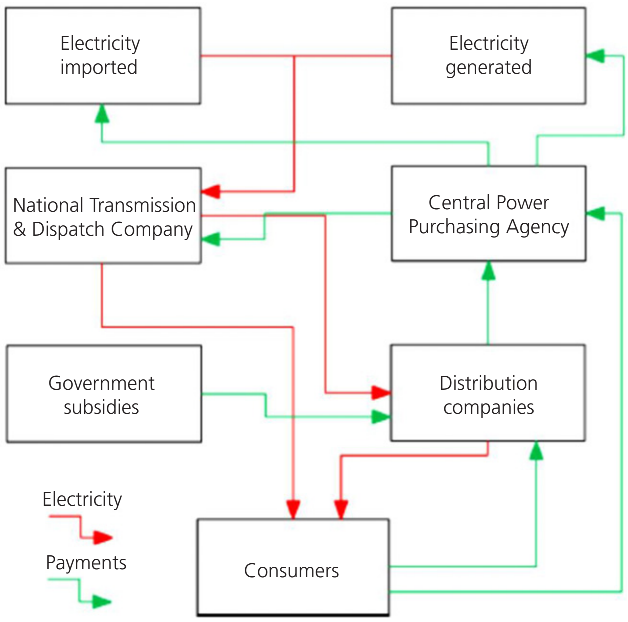

Figure 5. Involvement of different power sector entities responsible for electricity supply to the end users in Pakistan (Valasai *et al.*, 2017)

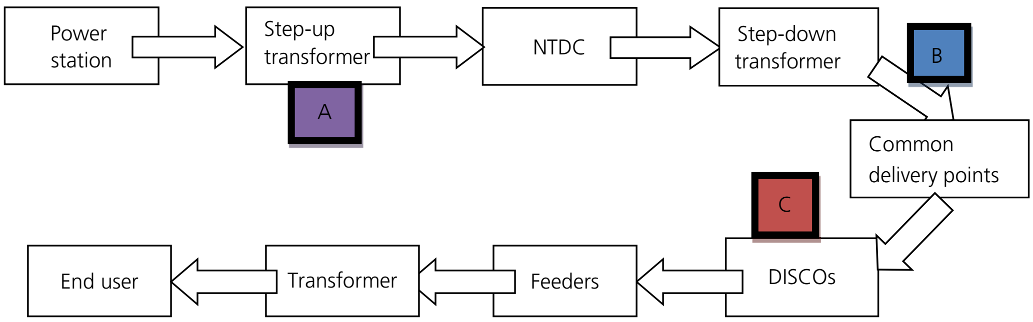

Figure 6. Electricity T&D network in Pakistan

Referring to Figure 6: energy lost between points A and B is technically called transmission loss, whereas energy lost from point B onward is called distribution loss. While there are no sources in Pakistan for receiving meter readings at points B and C in real time, the country ranks as the 14th highest among 131 countries considered for the level of electricity T&D losses (Bhatti *et al.*, 2015), with the NEPRA allowing for transmission and distribution losses of 3% and 10%, respectively. However, the combined T&D losses (expressed as percentages of the actual electricity generation at the power plants) for the NTDC and KESC networks in Pakistan are actually substantially greater, standing at approximately 20% and 32%, respectively, for the period 2010–2016 (see Figure 7), These T&D losses are very high when compared with other countries; for example they are significantly greater than the T&D losses of 8%, 7% and 4% reported for China, the Organisation for Economic Co-operation and Development (OECD) and Korea, respectively (Malik (2012), cited by Shakeel *et al.* (2016)), and the worldwide average value of approximately 9% reported for the period 2011–2013 (USEIA, 2016). The primary causes cited for the electricity distribution losses in Pakistan are theft and the improper recording or reporting of electricity metering devices, with such non-technical losses estimated to account for over 33% of the total distribution system losses (Kessides, 2013). Electricity theft adversely impacts on the quality of electricity supply by increasing the load on the power-generation plants (Depuru *et al.*, 2011) and also puts an added burden on paying customers through rising tariffs, although the price is often paid through government subsidies. The inevitable results of the presented picture are looming capacity shortfalls, load shedding and a raise in the public cost of electricity supply (Jamil, 2013).

Among other issues, the deprived electricity T&D network in Pakistan is a key reason for the massive build-up of circular debt (financial imbalances among the power sector entities) and the increasing electricity supply–demand gap. Substantial government subsidies provided to untargeted end users also culminate in massive circular debt; for example, the GoP paid approximately US$3 billion per annum in subsidies to end users from 2010 to 2014 (Shakeel *et al.*, 2016). Further details on the phenomenon of circular debt can be found in the papers by Khan and Abbas (2016) and Valasai *et al.* (2017).

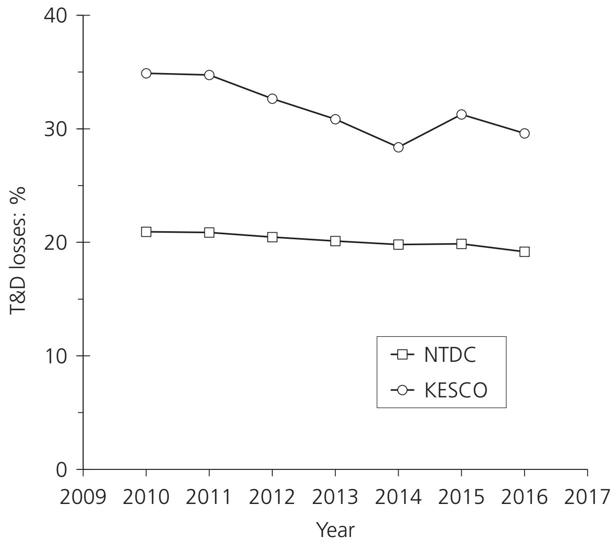

Figure 7. Electricity losses (based on net generation) during the T&D process (NTDC, 2017)

According to Shaikh *et al.* (2015), even if the existing electricity power-generation plants were geared up to operate at three-quarters of their capacities, the country's present T&D network simply does not have a capable and reliable infrastructure to distribute this power level to end users. In other words, the limitations of the present T&D network are such that the country's actual generated electricity power remains substantially lower than the peak electricity demand (Mirza *et al.*, 2008). As such, reducing the T&D losses (and achieving other energy efficiencies) must rank among the highest priority energy strategies. In this regard, a number of government policy assessments and technical and administrative actions are recommended to reduce electricity losses, mainly requiring extra investments in improving the T&D infrastructure and achieving greater operational and management efficiencies from generation to the end users (Bhatti *et al.*, 2015).

3. Wind power

3.1 Overview of the technology

The increasing electricity demand with arguably inflated energy prices and real environmental concerns arising particularly from fossil-fuel-based energy sources has created a move worldwide to the utilisation of green energy sources. Globally, wind power plants represent the largest single source (at nearly 50%) contributing to the increase in pollution-free electricity generation through RE resources, with almost 97% of all existing wind farms installed in the top and emerging markets; that is, the European Union, the United States, China and India (WWEA, 2015). Between 2011 and 2016, the share of wind power of global electricity demand increased from 2 to 4% and this may reach up to 20–41% by 2050 (GWEC, 2017; WWEA, 2015).

As discussed earlier, the wind-power industry is at an early stage in Pakistan, such that, to date, only onshore wind-power projects have been developed or are being considered in the country. Figure 8 illustrates the main components of an onshore wind-turbine system supported by a typical gravity-base foundation (GBF). The turbines harness the wind's kinetic energy, providing the motive force to turn rotor blades and produce electricity by way of a rotor drive shaft, gears and a generator located in the nacelle unit. A critical determining factor for the wind power achievable at a particular site location is the rotor diameter, with longer blades covering more swept area, thereby capturing more energy from the passing wind (Şahin, 2004); however, this also mobilises a greater bending moment to be resisted by the foundation. Cast-in-situ reinforced concrete GBFs are invariably employed to resist the system of vertical, horizontal, moment and torsional loads arising from the self-weight and wind loading acting on the wind-turbine structure. The GBFs are normally octagonal in plan, or may be square or circular, with a characteristic width (diameter) of typically 15–20 m, and are usually founded at 2–3 m depth below ground level. Depending on the rated power-generation capacity of the wind turbine, the concrete volume required for one GBF may be up to 500 m^3, with the excavated soil usually backfilled over the concrete slab foundation, thereby increasing its dead weight. A piled-raft foundation is typically used where the near-surface soil deposits provide insufficient allowable bearing pressure for GBFs. The foundations are designed to provide an adequate factor of safety against uplift, overturning, sliding and bearing-capacity failure modes and to limit (differential) settlement (i.e. tilting of the support tower) occurring over the project's design life within allowable limits. An important part of the design involves the analyses of the foundation response to the dynamic loading generated by wind turbulence blade–tower interaction as well as its seismic performance in earthquake-prone regions.

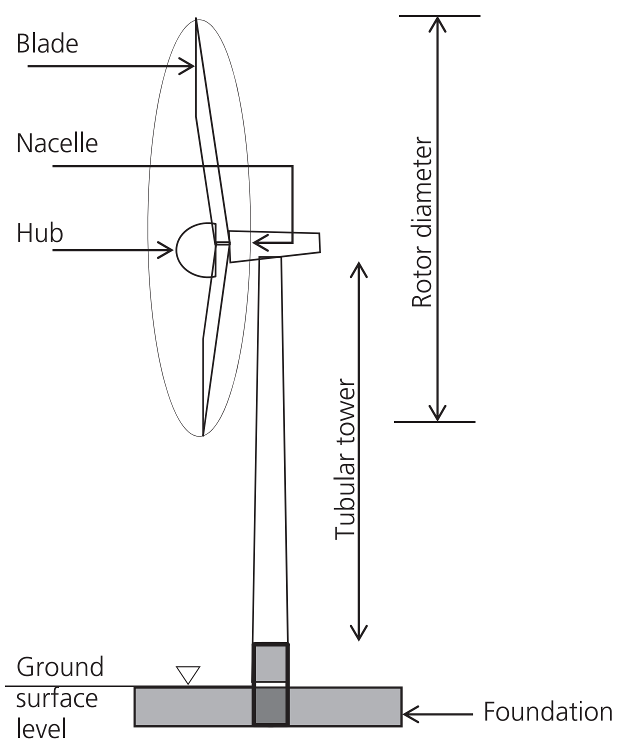

Figure 8. Main parts of an onshore wind-turbine system

The levelised cost of energy (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different energy-generating technologies. For wind power, LCOE represents the sum of all costs (i.e. including capital, operational and maintenance costs) over the project's lifetime, with financial flows discounted to a common year (Bhutto *et al.*, 2013). The LCOE for onshore wind power varies by country, technology and project, although it typically ranges 0·04–0·16 US$/kWh globally (REN21, 2015) and is below 0·068 US$/kWh for most projects located in higher source areas, including the United States, Brazil, Sweden and Mexico (REN21, 2015). The latter value compares favourably with estimated current average LCOEs of 0·067 and 0·056 US$/kWh for coal- and gas-fired power plants, respectively (Bhutto *et al.*, 2013). In Pakistan, the NEPRA-recommended LCOE value of approximately 0·10 US$/kWh was applied for most of the wind power projects presently under construction in the country, with this value reasonably on the lower side when compared with other RE resources, including solar, biogas and geothermal (Ali *et al.*, 2015). Mengal *et al.* (2014) have empirically established that when compared with oil- and gas-fired power generation in the country, wind power is potentially the cheapest source of electricity generation for Pakistan.

Table 1. Classification of wind power potential (Elliott, 2011)

Wind power class	Resource potential	Wind power density at 50 m AGL: W/m^2	Wind speed at 50 m AGL: m/s
1	Poor	0–200	0–5·4
2	Marginal	200–300	5·4–6·2
3	Fair	300–400	6·2–6·9
4	Good	400–500	6·9–7·4
5	Excellent	500–600	7·4–7·8
6	Outstanding	600–800	7·8–8·6
7	Superb	>800	>8·6

AGL, above ground level

3.2 Wind-power-generation potential in Pakistan

The feasibility analysis for any wind power project involves many stages, with the first step invariably requiring the selection of a suitable site location for the project, wind speed being one key determining factor (Awan and Khan, 2014). For this purpose, the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy has categorised wind-power potential into seven classes according to the wind power density and speed at an elevation of 50 m above the ground level (AGL) for the particular site location under consideration (see Table 1).

For a complete assessment of the proposed site location and the viability of harvesting any RE resource, however, one often needs to consider different types of potentials (Awan and Khan, 2014; Farooq and Kumar, 2013); for instance, theoretical, geographical, technical, techno-economic and economic potentials (Farooq and Kumar, 2013; Hoogwijk, 2004; Raja *et al*., 1996), which are briefly explained as follows.

- Theoretical potential is the highest level of resource potential and only takes into account restrictions concerning natural and climatic parameters.
- Geographical potential is the theoretical potential limited by the resources at geographic locations that are suitable for the installation of specific technologies, such as wind farms.
- Technical potential is the geographical potential that can be attained using available technologies, while accounting for conversion efficiencies.
- Techno-economic potential is that achievable by applying technically feasible and economically viable technologies that are universally used in competitive markets.
- Economic potential is the technical potential at cost levels considered competitive.

To date, the wind power potential of Pakistan has neither been utilised significantly nor estimated confidently due to the lack of reliable and complete data for windy corridors across the country (Mirza *et al*., 2007), with various agencies and researchers reporting widely different estimates for the country's exploitable wind power potential. Based on the wind map developed by the U.S. Department of Energy's NREL, and assuming 3% of the total land area of Pakistan has good or excellent wind resources, there is approximately 346 GW of wind power potential in Pakistan (Baloch *et al*., 2016; Elliott, 2011; Mengal *et al*., 2014), of which 120 GW can be realistically harvested (Farooqui, 2014; Ghafoor *et al*., 2016). Based on satellite mapping performed by the U.S. Agency for International Development in collaboration with the NREL, Mirza *et al*. (2015) reported an estimated gross exploitable wind-power potential for the entire country of 132 GW, with the most promising wind corridor of Gharo-Keti Bandar, located in the southern coastal region, offering an estimated potential of 50 GW. Farooq and Kumar (2013) reported that for Pakistan, commercially exploitable wind-power potential is found only in southern Pakistan, with the gross wind-power potential in the coastal areas of the Sindh and Balochistan provinces estimated at 43 GW, based on a suitable area for wind power generation of 9700 km^2, although according to Chaudhry and Afzaal (2004), various land utilisation constraints would limit this potential to 11 GW. Excluding low-wind areas and assuming a wind-power density of 5·4 W/m^2, Harijan *et al*. (2011) estimated the potential for electricity generation from wind along Pakistan's coastline as 123 GW. Ghayur (2006) and Mirza *et al*. (2010) indicated that 50 GW of wind power potential exists along the country's coastal areas, with an average wind speed of typically more than 7 m/s at 80 m AGL. For the Sindh province coastline, electricity-generation potentials from wind of 50 GW (Boyd, 2009) and up to 20 GW (Sheikh, 2010) were identified for reported monthly average wind speeds of approximately 8 and 5–12 m/s, respectively. Notwithstanding the differences in these reported exploitable wind power potential values, Pakistan's coastal areas, and especially the wind corridor in the Gharo region, appear ideal for generating electricity from wind energy.

Table 2. Wind resource at 50 m AGL for electricity generation in Pakistan (Elliott, 2011)

Wind class	Wind speed: m/s	Land area: km^2	Electricity potential: GW
4	6·9–7·4	18 106	90
5	7·4–7·8	5218	26
6	7·8–8·6	2495	12
7	>8·6	543	7
	Total	26 362	135

A summary of the wind resource at 50 m AGL for Pakistan, along with the potential for electricity generation from the country's estimated exploitable wind resources, are presented in

Table 2, with the following regions particularly identified as having good or excellent wind resources (Elliott, 2011).

- South-eastern Pakistan, especially the Hyderabad to Gharo region in the southern Indus valley, the coastal areas south of Karachi and the hills and ridges between Karachi and Hyderabad.
- Northern Indus valley, especially the hills and ridges in northern Punjab and the ridges and wind corridors near Mardan and Islamabad.
- South-western Pakistan, especially near Nokkundi and the hills and ridges in the Chagai and Makran areas.
- Elevated mountain summits and ridge crests, especially in northern Pakistan.

Vast areas of the Punjab and the northern areas of the country were reported as not suitable for exploiting wind energy for electricity generation (see PMD, 2018).

3.3 Forecast diffusion of wind power in Pakistan

The GoP has set targets for its Alternative Energy Development Board (AEDB) to install wind power plants having a combined capacity of 9·7 GW by 2030; that is 5% of the total planned national power-generation capacity at that time (Harijan *et al.*, 2011; Valasai *et al.*, 2017). Wind power plants having a combined capacity of 900 MW were operational at the time of writing this paper, with a further 700 MW of installed capacity anticipated by mid-2019. Further, as documented by Harijan *et al.* (2011), the AEDB has issued more than 94 letters of intent to private sector wind-power investors for 50 MW capacity sites; if fully realised, these projects would collectively represent an additional 4·7 GW generation capacity.

Harijan *et al.* (2011) forecasted that by 2030, approximately 50·6, 69·6 and 87·7 GW of wind power projects could be installed in Pakistan for standard, moderate and optimistic scenarios, respectively, representing approximately 42, 58 and 73% of the reported total wind-power-generation technical potential of 120 GW for the country (Farooqui, 2014; Ghafoor *et al.*, 2016). Further, by 2030, wind power plants could generate 111, 152 and 192 TW-h of electricity for the identified standard, moderate and optimistic scenarios, respectively. Based on a capacity factor value of 25%, AEDB estimated that the standard scenario investigated equates to 12·5 and 25 GW of wind-power addition to the electricity grid by 2030 and 2036, respectively (Farooqui, 2014).

3.4 Snags for the realisation of wind power generation in Pakistan

As described earlier in the paper and as reported by Sahir and Qureshi (2008), wind is the most promising RE resource for electricity generation in Pakistan, although, to date, this resource has been significantly underutilised, with the main reasons cited for the limited private sector investment and slow progress in the development of wind power projects given as the following.

- Low credibility and capacity of pertinent regulatory and monitoring bodies (Perwez *et al.*, 2015).
- Administrative delays and (or) technical uncertainties arising from, for instance: (*i*) time-consuming administrative procedures associated with the issuance of different types of licences and approvals (Mirza *et al.*, 2009; Rauf *et al.*, 2015); (*ii*) lack of reliable countrywide wind speed data and general absence of wind data for remote locations suitable for wind farm installations (Ghafoor *et al.*, 2016).
- Lack of infrastructure and logistic support; for example undependable grid connection capacity, poor manufacturing facilities and transport services (Shaikh *et al.*, 2015), which demand additional capital investments, thereby undermining the cost-effectiveness and economic viability of the wind and other RE power projects.
- Relatively poor state and underinvestment in research and development (R&D) facilities in the country (Ghafoor *et al.*, 2016) and the knock-on effect of insufficient numbers of adequately trained indigenous personnel (Farooqui, 2014; Shaikh, *et al.*, 2015).
- Insufficient release of funds for advancing RE projects, with the implementation of these projects likely to cause technological evolution in the industry (Rauf *et al.*, 2015).

A couple of these points are elaborated further. Despite the establishment of the Pakistan Council for Renewable Energy Technology (PCRET) in 2001 (mandated with the development of RE projects in the country) and the AEDB in 2003, most degree-awarding institutes and universities in Pakistan unfortunately remain deficient in specialised laboratories and (or) equipment necessary for performing high-quality research work in the field of wind-power engineering, with a knock-on effect that sufficient numbers of adequately trained personnel are not being produced annually to meet the industry needs in Pakistan.

The lack or absence of reliable wind speed data for the country prevents realistic assessments of the wind-energy potentials for possible wind farm sites. To assemble the wind climatology necessary for a reasonable assessment of the wind-energy resource at an identified site, a minimum 1 year period of wind measurements is required (Al-Yahyai *et al.*, 2010; AWS Scientific, 1997; Ganesan and Ahmed, 2008), with the associated degree of uncertainty typically ranging 5–15% (Frandsen and Christensen, 1992). Realistic assessment of the wind-energy potential requires statistical analysis of the wind data, including wind speed (preferably recorded at hub height), speed-frequency distribution, wind shear (i.e. rate of change in wind speed with elevation AGL), turbulence intensity (i.e. standard deviation of wind speeds sampled over 10 min period as a function of mean speed), wind direction distribution and also for extreme wind gusts having return periods of up to 50 and 100 years (Arshad and O'Kelly, 2013; DNV, 2014).

4. Suggestions for promoting rapid development of wind power projects in Pakistan

A multidisciplinary approach is required to make the wind-power industry more cost-effective and for the faster development of wind power projects, including the following.

- Implementation of more effective policies and strengthening of regulatory frameworks should encourage more private sector investment and participation in renewable electricity production, as well as with associated retail and revenue collection (Kessides, 2013), with effective monitoring and evaluation systems involving third-party validation and endorsement criteria proposed at the governance level (Qazi *et al.*, 2017).
- Development of transparent, fair and consistent investor-friendly national RE policies and legislations designed to shift the overreliance on electricity production from fossil fuels to RE resources, with due consideration for tax rebates, financial leasing and surety on safe investment through banks and (or) institutions (Shakeel *et al.*, 2016). Current heavy government subsidies for fossil fuels should be dissuaded in order to encourage and improve the adaptability of wind power production as a profitable business and investment (Bhutto *et al.*, 2013; Mirza *et al.*, 2009).
- Transformation of the AEDB and PCRET entities by the GoP into state-of-the-art institutions, as well as the establishment and growth of R&D centres of excellence in the field of REs, in order to ensure the development of planned and future RE projects.
- Science and engineering universities and institutes should embed issues pertaining to the development and implementation of RE technologies, especially for wind-power generation, in undergraduate and graduate curricula, combining analytical with experimental methods in a research-intensive environment, with the dual aims of developing and refining appropriate RE technologies for sustainable development and providing sufficient numbers of trained personnel for the industry.
- Strategic investment in the electricity T&D network, grid connection infrastructure and logistic supports.
- Development of a comprehensive and reliable countrywide wind-speed database, commencing with particular locations identified as most suitable for wind farm installations.

5. Summary and recommendations

At present, the electricity-generation mix in Pakistan is highly skewed towards thermal electricity, with oil and natural gas leading the production. This situation is not sustainable for a number of reasons, including the increase in electricity-related carbon dioxide emissions and the likely rise in electricity prices that would make electricity unaffordable for the masses. The situation would be further aggravated in the absence of a modernised electricity T&D network and metering system. On the production side, the situation clearly demands fuel diversification, incorporating significantly increased utilisation of indigenous alternative-energy resources toward solving the country's present electricity crisis and furnishing longer-term electricity needs. Wind power is identified as the most promising of the available RE resources in Pakistan.

The following recommendations are made towards mitigating the present electricity crisis and significantly increasing the contribution of wind power to the country's total energy mix.

- Reductions in non-technical losses and enhancing investment attractiveness (for both thermal and renewable) are likely to facilitate improved and affordable electricity supply.
- Implementation of more effective, transparent and consistent policies, along with the strengthening of regulatory frameworks, for supporting greater renewable electricity production, combined with independent monitoring and evaluation at the governance level.
- Although there are some guidelines for the operation of IPPs, the private sector should be given appropriate roles in the T&D and retail of electricity to the end users.
- Fuel diversification achieved by means of new RE production plants, with those plants that can be developed within a relatively shorter time period being given preference. For instance, based on the actual situation observed in Pakistan over the past 10 years, medium-sized wind farms can be typically developed within a 1–2 year period, compared with the typically 5–7 year period required for hydropower plants having similar electricity-generation capacity.
- Upgrading and overhaul of the existing stock of thermal power plants and the electricity T&D infrastructure along with the application of smart electricity metering systems.
- Targeted government funding of the country's energy R&D sector for innovation, training, development of appropriate RE technologies and promotion of energy-saving technologies.
- A comprehensive study programme is required for the generation of a reliable countrywide database of wind-speed characteristics and statistics, commencing with

geographical regions identified as most promising for wind farm installations.
- Wide promotion campaign of an energy-efficiency policy, with due consideration for the implementation of the manufacturing standards on electrical appliances, so that substandard and inefficient devices may be withdrawn from the market.

From the authors' perspectives, the ensuing benefits from such reforms will not be fully realised without keen interest at the governance level of the country.

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