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Wind energy market in USA

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ABSTRACT

This paper reviews the development and the perspectives of the wind energy market in USA, particularly to identify its potential growth as renewable energy source for electric generation, and to provide researchers, and various agencies a better understanding of wind energy market opportunities and barriers in USA within global context. The history of wind energy development, the cost analysis of wind energy compared to others renewable resources and fossil fuels, the renewable energy barriers, the prospect, and cost of the wind energy for USA market and legal acts are all reviewed. USA renewable wind and solar energy sources are used today to generate direct electric power for direct use by utility power companies, industrial, commercial, residential, and transportation sectors. In 2021, USA produced 92.9 quadrillion Btu from different types of energy resources including fossil fuels (35% petroleum, 34% natural gas, and 10% coal), 9% nuclear energy, and 12% renewable sources of energy. USA wind turbine capacity showed a growth rate of 13.4% with 117.7 Gigawatts in 2020, and 11.7% growth rate over 2009-2010. The European and Asia Pacific wind capacities were higher in 2020 than US with 216.6 and 341.9 Gigawatts, respectively. However, the European wind capacity growth rate decreased to 5.9% in 2020 as compared to their 10.3% growth during 2009-2019. The Asia Pacific's wind capacity experienced firm growth at rate of 28.6% in 2020 and 23.0% during 2009-2019. Furthermore, the literature studies found that USA has become the world's second largest wind power consumption (approximately 21%) country in 2020. The geographic distribution of wind resources are 20 times greater than the total global energy consumption. The average construction cost of windmill is being declined due to the tax incentives, utility demand, and better technology. This study suggests that the government regulatory policies and their commitment for harnessing wind energy should be stable and clear. Feed-in-tariff and long-term financial subsidies will also promote the diffusion of wind power development.

Keywords: wind energy, renewable energy, renewable energy barriers, energy policies, energy market

INTRODUCTION

Energy is playing an essential role for the global development. The world's energy demand is increasing day-by-day. It is pushing forward the world into some unwanted challenges since energy security and reduction of carbon emission are also growing concerned issues for human being. Energy related carbon dioxide (CO_2) release is the main cause of the global warming and the climate change. 66% of the global greenhouse gas is due to man-made CO_2 production, which includes electricity production, transport in its all forms, burning fossil fuels (e.g., coal, oil, gas), deforestation etc. (Letcher, 2017). The renewable industry focuses on the sustainable energy sources that generate electricity free of CO_2 such as wind, solar, hydro, biomass, and geothermal etc. On the other hand, nonrenewable energy such as fossil fuels are limited in supply and unsustainable (Roy, 2002).

In 2020, the total estimated energy consumption from various sources of energy is 79.9% from fossil fuels, 2.2% from nuclear energy, 7.5% from traditional biomass, and 10.6% combining wind, solar, and hydropower (C2ES, 2020). According to Energy Information Administration data, the average capital cost of the energy production in (US$/kW, 2019 price) are: 1,331 for solar PV-utility, 1,319 for wind onshore, 5,446 for wind offshore, 2,680 for geothermal, 2,752 for hydro, 6,317 for nuclear, and 2,831 for biomass (Timilsina, 2021). Among all the renewable sources, wind power has appraised as one of the most favorable sources of sustainable energy in many countries of the world because of its commercial viability, and technical feasibility (Roy, 2002). Berry mentioned that the expectation of wind energy maturation market exceeds its self- sustainability limit, reduce the environmental impacts, and high capital costs by proving itself as an impulsive factor of production and energy supply (Berry, 2009).

However, the total global consumption rate from renewable sources was 18% in 2017. The total global electricity generation from renewable sources in 2018 was about 26.2% which is expected to rise 45% by 2040. Most of the

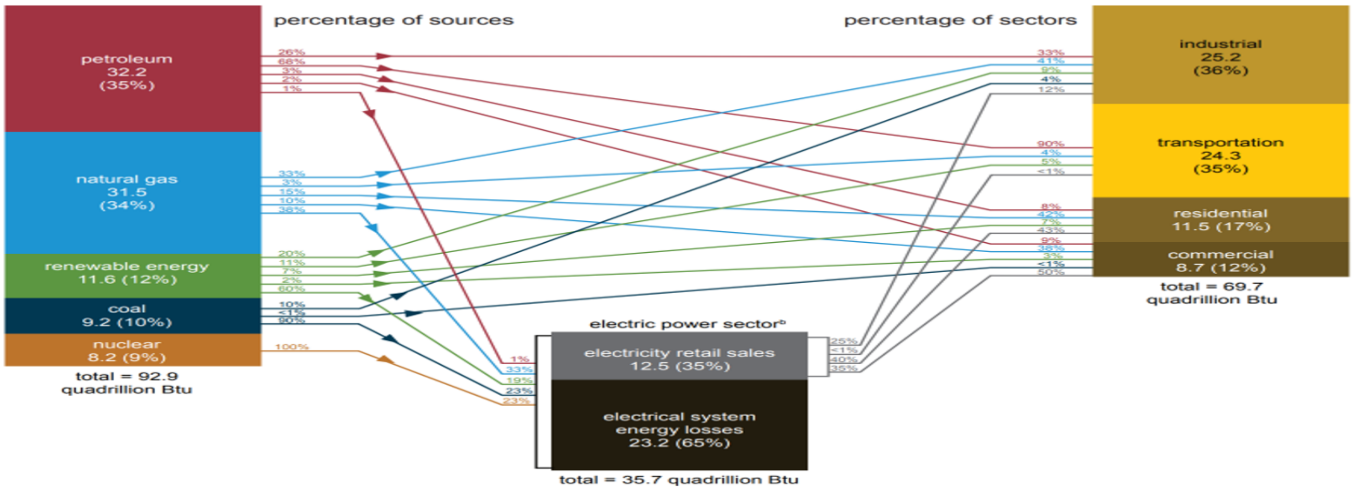

Figure 1. Energy source & distribution: USA energy consumption by source & sector, 2020 quadrillion Btu (USA EIA, 2021b)

enhancement will be expected to come from wind, solar and hydro power. Renewable energy is the fastest growing energy sources in USA. It produced more than 17% of the net USA electricity generation from renewable sources in 2018 and the consumption rate was 12% (Charlier, 2003). USA has become the world's second largest wind power consumption (approximately 21%) country in 2020 while China was the leading country based on its consumption rate (29%) (Jaganmohan, 2021).

Wind is available for generating power in each corner of the world except the heavily forested areas of the Amazon, Congo, and Southeast Asia. In geographic distribution, wind resources are immeasurable, which is 20 times greater than the total global energy consumption (Dabiri et al., 2015). In 2018, the total electricity generation from renewable sources was about 28% and consumption was about 15% (USA EIA, 2021a). In 2020, the worldwide cumulative wind power installed capacity was nearly 743 gigawatts (Jaganmohan, 2021). However, USA produced 338 billion KWh energy which is about 8.4% of total utility scale electricity generation in 2020. The consumption rate of wind energy was about 26% among USA renewable energies (USA EIA, 2021a).

The wind energy technology is far behind though it has a potential market in worldwide. There are only four European countries who are producing more than 10% of electricity from wind. Only 4% of the electricity is generated from wind in USA although there are so many potential locations in producing wind energy (Dabiri et al., 2015). It is a rapidly growing energy source which is available in large areas in both onshore and offshore in USA. There are some barriers to use the abundance of wind energy resources and the adoption of existing wind energy technologies in USA such as economic, infrastructure, regulatory, and cultural issues. Furthermore, the current wind power system is challenging because of random fluctuations and intermittence of wind power though it is available in large areas. On the other hand, the global primary energy sources comprise commercially traded fuels, including modern renewables used to generate electricity. Energy from all sources of non-fossil power generation is accounted for on an input-equivalent basis.

Researchers created prediction models to show possibility of USA to reach 100% renewable energy electric power systems by 2050 using existing technologies (Cole et al., 2021). However, USA may face challenges in expanding its share of renewable energy consumption. Such challenges include the need create policies that re-enforce the national security and ensure clean energy development (Alola and Saint Akadiri, 2021). Other studies related the wind energy growth to a much more complex problem that involve tradeoffs between wind turbine design, land access constraint, ecological, wildlife, noise, visual factors, regulatory restrictions, technology innovation, power system infrastructure, turbine tip heights setbacks, and return in investment (Lopez et al., 2021).

This paper provides a literature survey and summary of statistical data on the development of wind energy in USA. Next section surveys the current wind energy generation in US. and the world, and then compare it with other energy resources. A brief history of the world's wind energy and USA market developments are then presented, respectively. After that we further examine the cost of wind farm installation and prices trend. Then we discuss the renewable energy policies such as federal, state rules, feed-in-tariff (FIT), and regulations. We then examine the factors that limit the growth of wind energy in USA, which include environmental, social, technological, economic, and regulatory barriers. Finally, we provide the authors assessment and recommendation.

ENERGY STATISTICAL DATA: SOURCES, GENERATION, CONSUMPTION, AND RENEWABLE IN USA COMPARED TO THE WORLD

USA uses and produces many different types and sources of energy. The primary energy sources include fossil fuels (petroleum, natural gas, and coal), nuclear energy, and renewable sources of energy. It is predicted that renewable sources–particularly solar and wind–will become predominant over the years (Elavarasan, 2019). The chart in **Figure 1** shows the amounts of primary energy sources consumed by the electric power sector and the energy end-use sectors.

As of 2021, USA produced 92.9 quadrillion Btu from all available energy resources, out of which 35.7 quadrillion Btu

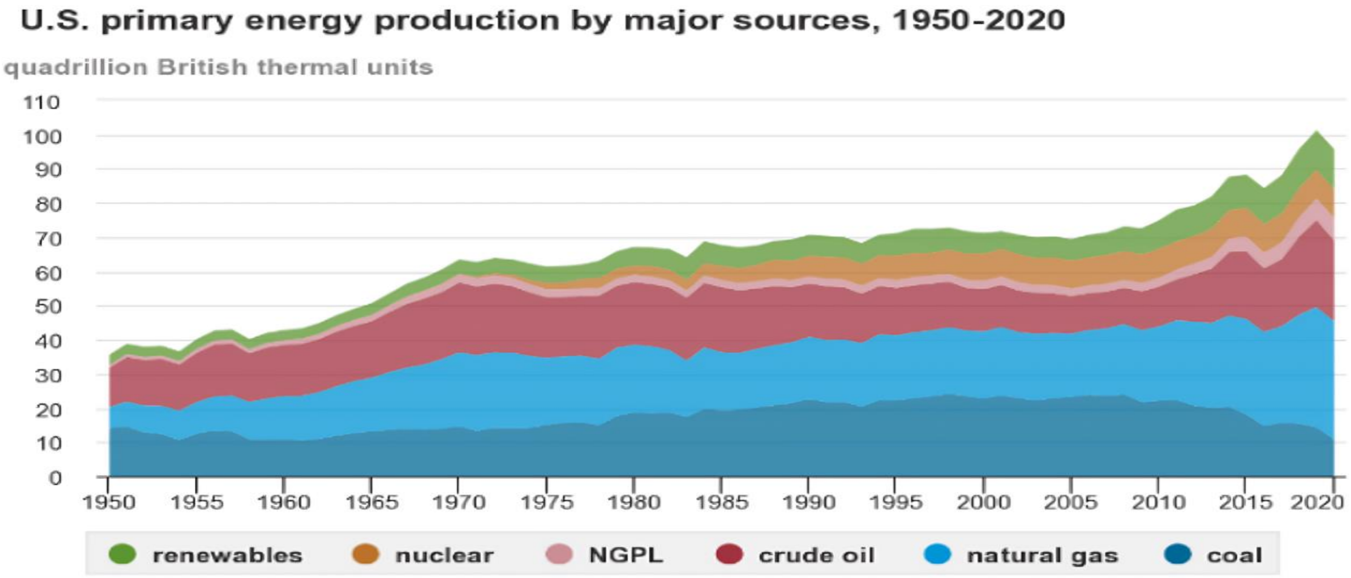

Figure 2. Energy source & distribution: Main energy sources in USA (USA EIA, 2021b)

Table 1. Primary energy consumption (BP, 2021)

											GRPA (%)		
ExaJoules	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020**	**2009-19**	**S-2020**
TNA	113.50	113.49	111.14	113.92	114.88	114.04	113.85	114.40	117.92	116.90	**107.90**	-8.0	0.6	19.4
TSCA	26.19	27.27	27.99	28.70	28.89	28.97	28.53	28.75	28.58	28.33	**26.19**	-7.8	1.3	4.7
TE	88.53	86.50	86.18	85.29	82.01	82.72	83.81	84.64	84.74	83.46	**77.15**	-7.8	-0.2	13.9
TCIS	35.23	36.71	37.10	36.53	36.82	36.41	36.88	37.30	39.08	38.90	**37.12**	-4.8	1.4	6.7
TME	29.33	30.63	31.84	32.68	33.83	34.82	35.82	36.30	36.47	37.51	**36.44**	-3.1	3.1	6.5
TA	15.99	16.04	16.64	17.10	17.75	18.09	18.59	19.03	19.50	19.87	**18.58**	-6.7	2.5	3.3
TAP	196.60	206.99	213.73	220.09	225.38	229.36	234.24	241.41	249.85	256.54	**253.25**	-1.6	3.3	45.5
USA	92.91	92.05	89.62	92.04	92.99	92.09	91.96	92.26	95.64	94.90	**87.79**	-7.7	0.5	15.8

Note. TNA: Total North America; TSCA: Total South & Central America; TE: Total Europe; TCIS: Total Commonwealth Independent States; TME: Total Middle East; TA: Total Africa; TAP: Total Asia Pacific; GRPA: Growth rate per annum; & S-2000: Share 2000

Table 2. CO_2 emissions in USA compared to the rest of the world studied over the past 10 years (BP, 2021)

												GRPA (%)	
MTCO₂	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020**	**2009-19**	**S-2020**
TNA	6,499.9	6,376.1	6,129.4	6,316.1	6,320.5	6,211.0	6,094.5	6,055.2	6,219.4	6,067.1	**5,348.1**	-12.1	-0.4	16.6
TSCA	1,198.5	1,254.1	1,308.2	1,365.0	1,385.7	1,381.9	1,339.7	1,322.7	1,293.8	1,274.5	**1,157.7**	-9.4	1.3	3.6
TE	4,677.5	4,600.4	4,541.3	4,434.7	4,204.1	4,212.4	4,260.8	4,300.5	4,251.0	4,091.3	**3,596.8**	-12.3	-1.1	11.1
TCIS	1,980.9	2,082.3	2,115.7	2,093.5	2,100.5	2,073.4	2,080.4	2,075.6	2,179.7	2,165.6	**2,039.5**	-6.1	1.2	6.3
TME	1,765.6	1,828.1	1,901.2	1,967.1	2,016.1	2,064.8	2,131.8	2,143.9	2,146.9	2,190.2	**2,110.1**	-3.9	2.7	6.5
TA	1,171.6	1,162.0	1,198.4	1,227.8	1,263.6	1,274.4	1,306.2	1,327.9	1,342.7	1,364.5	**1,254.0**	-8.4	1.8	3.9
TAP	13,997.5	14,869.5	15,309.8	15,667.0	15,850.1	15,988.3	16,148.5	16,501.1	16,917.6	17,203.3	**16,778.0**	-2.7	2.6	52.0
USA	5,495.0	5,348.4	5,101.5	5,268.3	5,277.6	5,165.6	5,060.8	5,003.2	5,166.0	5,029.4	**4,457.2**	-11.6	-0.5	13.8

Note. $MTCO_2$: Million tones of CO_2; TNA: Total North America; TSCA: Total South & Central America; TE: Total Europe; TCIS: Total CIS; TME: Total Middle East; TA: Total Africa; TAP: Total Asia Pacific; GRPA: Growth Rate Per Annum; & S-2000: Share 2000

went directly to electric power sector and 69.7 quadrillion was consumed by major sectors to include 35% in transportation, 36% in industrial and manufacturing plants, 17% in residential buildings, and 12% in commercial buildings. Renewable energy provided 12% of energy resources where 19% of its net production went to electric power companies and the remaining was directly consumed by other major sectors.

Figure 1 shows that the transmission of the electricity generated by renewable energy experiences a substantial loss as compared to other energy sources because it depends on long or remote network of power grids. In USA, the petroleum provides only 1% of the electric power sector's primary energy use, and approximately 90% of the transportation sector's energy consumption.

The mix of USA energy consumption and production has changed over time. For example, renewable energy production and consumption both reached record highs in 2020 as shown in **Figure 2**, driven mainly by solar and wind energy production.

Table 1, **Table 2**, and **Table 3** compare the energy consumption, CO_2 emission and electric generation in USA to the rest of the world studied over the past ten years.

The growth in energy markets slowed in USA in 2019. China was by far the biggest individual driver of primary energy

Table 3. Electricity generation data in USA compared to the rest of the world studied over the past 10 years (BP, 2021)

											GRPA (%)		
TH	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020**	**2009-19**	**S-2020**
TNA	5,276.8	5,293.8	5,243.5	5,283.1	5,314.2	5,318.4	5,331.1	5,287.7	5,452.5	5,382.4	**5,243.6**	-2.8	0.6	19.5
TSCA	1,140.5	1,181.1	1,231.4	1,267.6	1,287.3	1,296.6	1,305.6	1,306.8	1,330.9	1,339.0	**1,282.8**	-4.5	2.1	4.8
TE	4,065.8	4,019.4	4,053.1	4,022.2	3,939.2	3,982.7	4,021.4	4,061.3	4,065.5	3,992.1	**3,871.3**	-3.3	0.2	14.4
TCIS	1,284.0	1,308.5	1,330.4	1,323.7	1,337.9	1,340.9	1,369.3	1,383.0	1,416.4	1,428.8	**1,397.1**	-2.5	1.5	5.2
TME	873.7	889.7	948.6	982.4	1,051.4	1,109.7	1,143.7	1,190.5	1,207.4	1,253.6	**1,265.2**	0.6	4.5	4.7
TA	672.3	689.4	721.1	744.0	767.9	788.4	796.5	824.8	847.2	863.4	**843.9**	-2.5	3.2	3.1
TAP	8,257.7	8,875.1	9,278.1	9,812.3	10,333.7	10,433.9	10,947.6	11,569.8	12,339.3	12,741.6	**12,919.3**	1.1	5.4	48.2
USA	4,394.3	4,363.4	4,310.6	4,330.3	4,363.3	4,348.7	4,347.9	4,302.5	4,461.6	4,411.2	**4,286.6**	-3.1	0.5	16.0

Note. TH: Terawatt-Hours; TNA: Total North America; TSCA: Total South & Central America; TE: Total Europe; TCIS: Total CIS; TME: Total Middle East; TA: Total Africa; TAP: Total Asia Pacific; GRPA: Growth Rate Per Annum; & S-2000: Share 2000

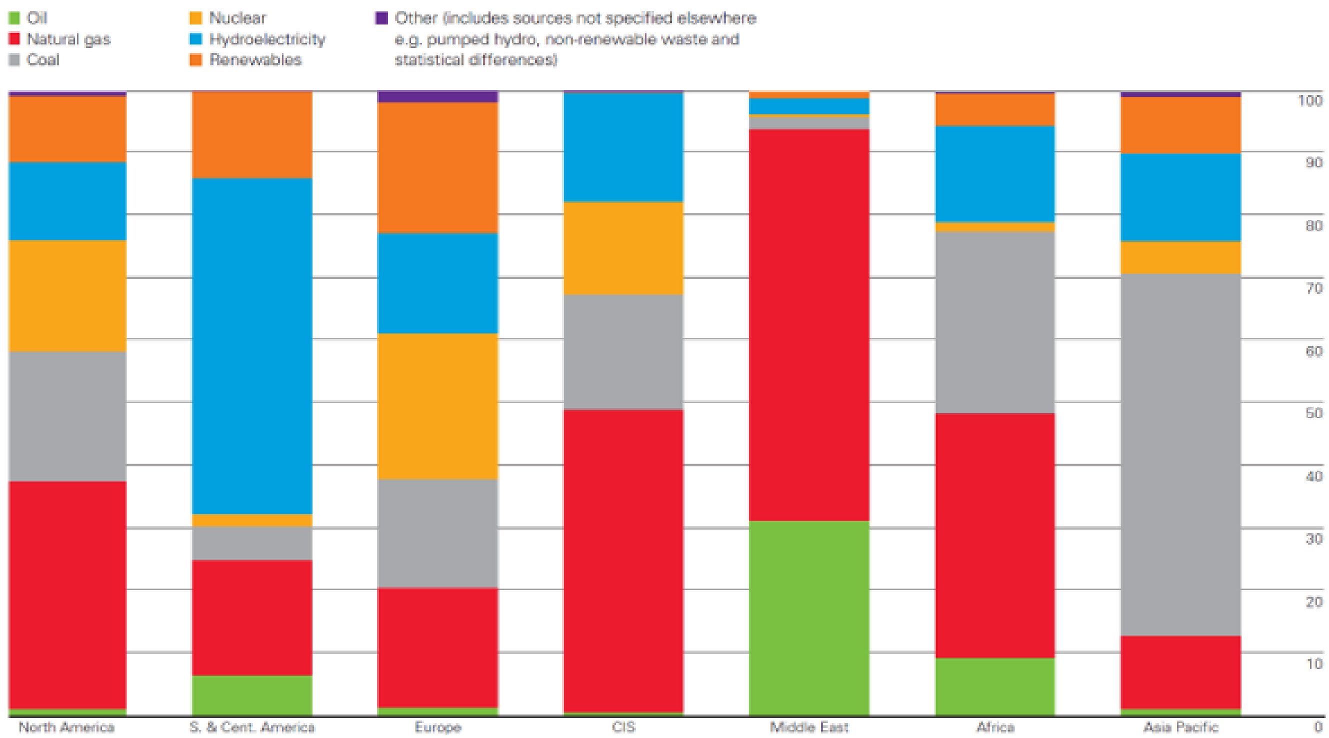

Figure 3. 2019 percentage of regional electricity generation by nuclear, coal, natural gas, renewables, and hydro (BP, 2021)

growth by region, consumption fell in North America, Europe, and CIS (commonwealth independent states) and the growth was below average in South and Central America. Demand growth in Africa, Middle East, and Asia did not change from historical averages. Significant slowdown in the growth of carbon emissions is observed due to slower growth in energy demand and a shift in the fuel mix away from coal and toward natural gas and renewables. Generation of electricity was weak or negative in most regions, other than in China, which accounted for 95% of net global growth.

The world's energy generation and usage show a promising outlook for renewable sources which has accounted for around 60% of the growth in global power generation over the past five years. One reason could be attribute to the costs of onshore wind and solar power, which have fallen by around 40% and 55%, respectively over the past five years (Energy, 2018). 2020 was a record year for the build-out of wind and solar capacity where China accounted for roughly half of the global increase in wind and solar capacity.

In 2020, the combination of the pandemic and economics have led world regional electricity generation to drop. **Figure 3** shows that the natural gas is the dominant fuel used for power generation in North America, CIS, the Middle East, and Africa. More than half of the power in South and Central America is hydroelectricity, while in Asia, coal comprises 57% of the generation mix–a far higher share than any other region. In Europe, renewables (including biopower) are the largest source of power generation with 23.8% for the first time, overtaking nuclear on 21.6%. Generation in Europe is spread evenly between renewables, nuclear, and gas (19.6%) and hydro (16.9%).

By renewable energy source (RES), wind generation provided the largest contribution to growth followed closely by solar. Wind and solar RESs are mainly used to generate electricity to the grid system due to ease of integration. Solar has constantly increased its share of renewable generation and now makes up 26% compared with only 14% five years earlier as depicted from data in **Table 4** and **Table 5**.

Table 4. Renewable solar energy capacity in USA compared to the rest of the world studied over the past 10 years (BP, 2021)

											GRPA (%)		
IPVP	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020**	**2009-19**	**S-2020**
TNA	2.3	5.7	9.0	13.1	17.9	24.4	36.0	44.9	57.1	66.7	**82.8**	23.8	48.2	11.7
TSCA	0.1	0.2	0.3	0.5	0.8	1.8	2.7	5.2	7.5	10.8	**15.1**	39.6	67.4	2.1
TE	30.1	53.6	71.7	81.9	88.8	97.5	104.7	113.5	124.4	146.3	**167.8**	14.4	24.1	23.7
TCIS	†	†	†	†	0.1	0.2	0.2	0.4	1.0	2.3	**3.2**	42.7	110.6	0.5
TME	0.1	0.2	0.3	0.5	0.8	1.0	1.5	2.1	3.3	5.5	**6.5**	18.6	62.7	0.9
TA	0.2	0.3	0.3	0.7	1.6	1.9	3.0	4.7	7.1	8.3	**9.5**	14.5	54.5	1.3
TAP	7.3	12.1	19.8	39.1	61.6	90.6	143.2	213.6	282.5	341.0	**422.6**	23.6	54.9	59.7
USA	2.0	5.2	8.1	11.8	16.0	21.7	33.0	41.4	51.4	58.9	**73.8**	24.9	47.8	10.4

Note. IPVP: Installed Photovoltaic Power (Gigawatts); TNA: Total North America; TSCA: Total South & Central America; TE: Total Europe; TCIS: Total CIS; TME: Total Middle East; TA: Total Africa; TAP: Total Asia Pacific; GRPA: Growth Rate Per Annum; & S-2000: Share 2000

Table 5. Renewable wind energy capacity in USA compared to the rest of the world studied over the past 10 years (BP, 2021)

												GRPA (%)	
WTC	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020**	**2009-19**	**S-2020**
TNA	43.6	51.5	67.1	69.9	76.5	87.1	97.3	104.2	112.1	123.6	**139.4**	12.5	12.5	19.0
TSCA	1.5	2.2	3.1	3.6	7.5	11.2	14.5	17.3	20.8	22.6	**26.4**	16.4	35.2	3.6
TE	86.2	96.4	109.4	121.0	133.8	147.5	161.5	177.1	189.0	203.9	**216.6**	5.9	10.3	29.5
TCIS	†	†	†	†	0.1	0.1	0.1	0.2	0.3	0.5	**1.5**	218	41.7	0.2
TME	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	**0.9**	18.7	22.5	0.1
TA	0.8	1.0	1.1	1.7	2.4	3.3	3.8	4.6	5.5	5.8	**6.5**	12.2	23.1	0.9
TAP	48.5	68.7	86.0	103.4	128.8	166.7	189.2	210.5	235.6	265.1	**341.9**	28.6	23.0	46.6
USA	39.1	45.7	59.1	60.0	64.2	72.6	81.3	87.6	94.4	103.6	**117.7**	13.4	11.7	16.1

Note. WTC: Wind Turbine Capacity (Gigawatts); TNA: Total North America; TSCA: Total South & Central America; TE: Total Europe; TCIS: Total CIS; TME: Total Middle East; TA: Total Africa; TAP: Total Asia Pacific; GRPA: Growth Rate Per Annum; & S-2000: Share 2000

Figure 4. Historical Dutch and farm windmills. Dutch windmill that was used to pump water for irrigation (left). Assorted designs of farm windmills at J. B. Buchanan Farm, Texas ® (Nelson, 2009)

HISTORY OF WIND POWER DEVELOPMENT

Once the wind was a major source of energy before the invention of the steam engine. Wind powers were used for transportation (e.g., sailboat), grinding grain, and pumping water.

The Dutch windmills in **Figure 4** were used the sail-wing blades to pump water for irrigation. The first vertical axis windmills were reported in the 10th century in Persia, and the 13th century in China. Netherland used to use assorted designs of windmills (e.g., the early post mills to taller mills) whose tops were rotated to keep the blade perpendicular to the wind. The top of the windmill was rotated with a rope that was attached to a wooden beam on the cap to run the rotor perpendicularly to the wind. The big rotors were rotated by using the small fan rotors (Nelson, 2009). By 1900, the metal made windmills were mostly used in farms that had multi blade vanes. The diameter of the blades was 3-5 m. The peak time of the use of farm windmill was 1930-1940s. Currently, most of the farm windmills are used in Africa, Argentina, Australia, Canada, and USA (Allen, 1976).

Figure 5. Several types of wind turbine that are based on propeller type rotor: urban green technology, air dolphin, honeywell, vertical axis wind spire, and sky stream wind turbine (from left to right)

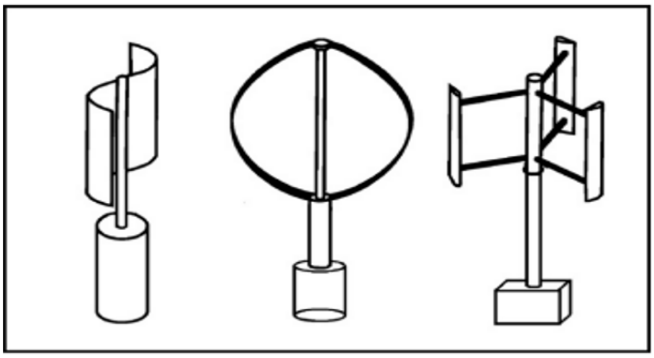

Figure 6. Different rotor designs: Savonius rotor, Darrieus wind rotor (vertical axis turbine), and horizontal rotor (from left to right) (Eriksson et al., 2008)

The proportion of the farm windmill energy market is small because of its estimated cost to produce electricity and maintenance. It was expensive to generate electricity from the power generating plants because the transmission lines were too costly in addition to the absence of power grid infrastructure back then. The reason is that some of the isolated locations of farm windmills were too far from the power generating plants. Therefore, several manufacturers built several types of wind systems that are based on propeller type rotor with two or three blades as shown in **Figure 5**. Most of these wind systems had direct current generators that were able to generate at most 110 V. The produced electricity from the propellor type rotor was stored in wet-cell-lead-acid batteries. These batteries required careful maintenance for long life. This wind system used most of the rotor swept area which is quite different from the farm windmills (Nelson, 2009).

Unique rotor designs were developed to construct large wind turbines for capturing wind energy such as air-foil shaped blades with horizontal and vertical rotor axes, Magnus effect, and Savonius designs as shown in **Figure 6** (National Renewable Energy Laboratory, 2021).

The air-foil shaped blade was developed by Marcellus Jacob, which had three blades, a battery storage, and a wind wane to keep the turbine against the wind (Manwell et al., 2010). The horizontal axis wind turbine (HAWT), which is bigger and more advanced turbine that was developed in 20th century. The vertical axis wind turbine (VAWT), which needs less financial support and less interest that was developed in parallel with HAWT. For example, VAWT is a prototype of Darrieus turbine, which is quite efficient and reliable. This turbine was built by Canada and USA. VAWT fell victims to the poor wind energy market in USA after found a crack on its foundation in 1997 (Eriksson et al., 2008).

The straight bladed VAWT, which is also known as straight-bladed Darrieus turbine or the H-rotor. The biggest H-rotor (500 KW machine) was built in UK, which was designed in 1989 (Mays et al., 1990). The German company Heidelberg Motor GmbH worked with development of H-rotors, and they built several 300 kW prototypes. There is a contradiction that HAWT is not better than VAWT. HAWT become more popular because and it was randomly picked for a large-scale development, and it received more attention. In several countries, the vertical axis turbines are more favorable in research project for tidal current power (Charlier, 2003).

REVIEW OF WIND ENERGY MARKET DEVELOPMENT IN USA

One of the derivers for wind energy growth in USA are fixed quotas and green certificate trading known as Renewable Portfolio Standard (RPS) (Kaygusuz, 2004). Industrial wind energy use in USA began in the late 1970s as part of a response to the oil embargo. New industry for producing standardized wind turbines began on 1980s and since then the industry has been developing rapidly (Vestergaard et al., 2004). For example, California wind rush in the 1980s boomed as a result of the state and government subsidies, where more than 4,600 Danish wind turbine was installed out of nearly 11,000 wind turbines in the state (Gipe & Möllerström, 2022).

The development of wind power market slowed down after booming the market in California during the mid of 1980s.The installation ability reduced because of disassembling the old wind farms was sometimes exceeded the installation of new wind turbines. Another wind power booming period was in 1998 in USA. Due to federal production tax credit, the wind power production developers aimed at installing projects before the tax credit expired on June 30, 1999. USA installed more than 800 MW of several new wind power generation in California wind farms between this time. Besides these, major projects were carried out in the states of Minnesota, Oregon, Wyoming, and Iowa in USA (Kaygusuz, 2004).

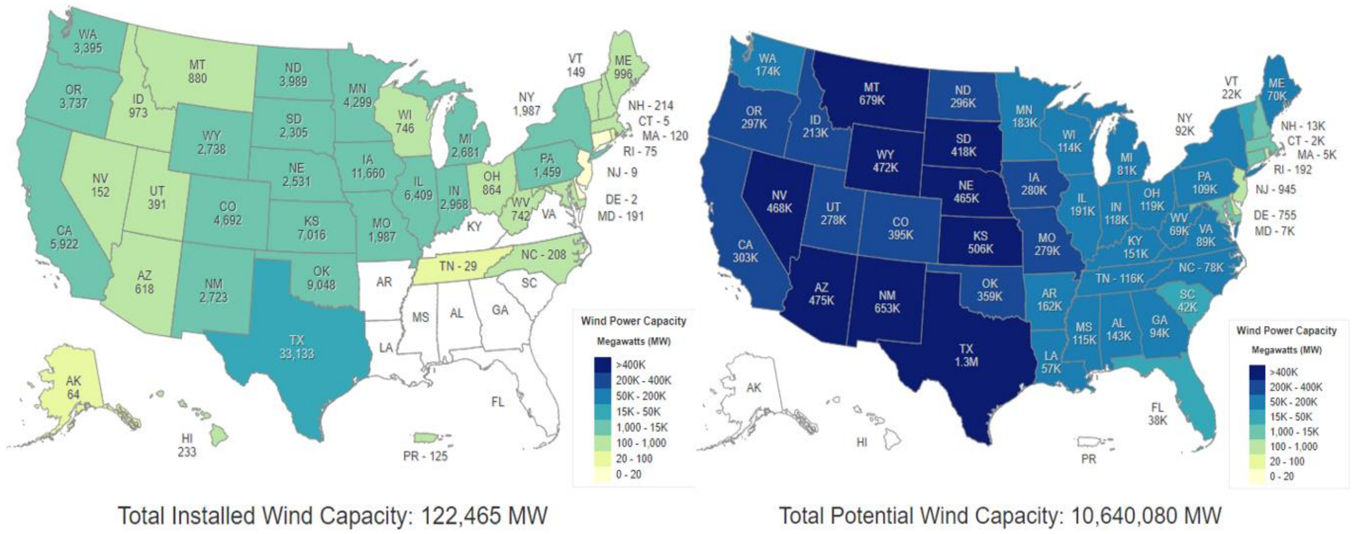

Figure 7. USA installed and potential wind power capacity and generation (Source: WINDExchange USA)

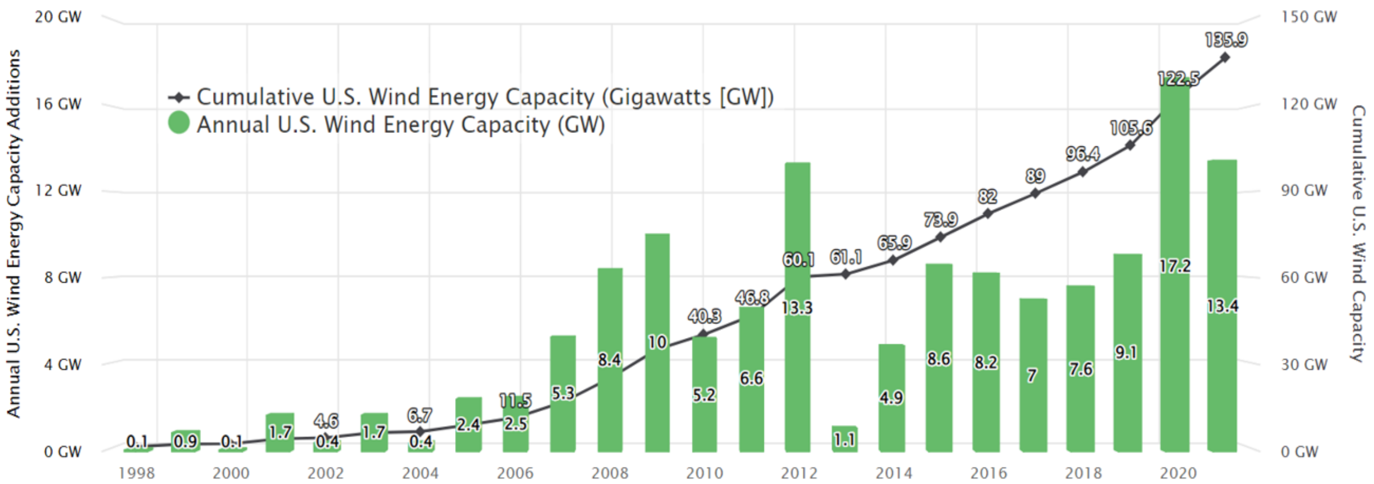

Figure 8. Chart data compiled from the wind technologies market reports from 2010-2019 and the land-based wind market reports 2021 and 2022 editions. In 2021, cumulative USA land-based wind energy capacity reached 135.9 GW (Energy, 2022)

Wind energy is one of the most promising alternative sources in USA. It can be achieved through the installation of wind turbine in both onshore and offshore. The report of USA Energy Department releases the vast potential of wind energy deployment in all 50 states, shown in **Figure 7**, which is possible through the next generation of larger wind turbines (Zayas et al., 2015). The largest wind turbines are capable to run within the planetary boundary layer and always experience turbulence in the wind.

The boundary layer varies in thickness from about 250 m (about the height of the Empire State Building) over sea to about 500 m (about twice the height of the Empire State Building) over cities and craggy country. The air movement is smooth above the boundary layer unless there are major storms or hurricanes. It is affecting the weather and planes, but not wind turbines directly if there is an unusual feature of jet streams at heights between about 10 km (about the height of Mount Everest) and 15 km (Twidell, 2021).

In USA, the typical wind turbines (e.g., 120-250 MW) installation started in 1998, which is usually larger wind farm projects compare to Europe. In Europe, projects are usually in between 20 MW and 50 MW because of limited space and high population density (Kaygusuz, 2004). European wind industry experienced peak in production from offshore wind farm because of these limitations (deCastro et al., 2019). In USA, the offshore wind energy potential was ignored since vast onshore wind resources have the potential to fulfill the electricity needs for the entire country (Kaygusuz, 2004). However, the challenges of transmitting the electricity to the large load centers may limit wind grid penetration for land-based turbines.

Offshore wind turbines can generate power much closer to higher value of coastal load centers. Since USA coastal area waters are deeper than the European coastal areas, it requires modern technology. The recent success of European offshore wind energy has inspired USA for harnessing offshore energy (Musial and Butterfield, 2004).

The capacity factor of a wind turbine is its average power output divided by its maximum power capability. USA wind power capacity grew at a strong pace in 2021, with 13.4 GW of new capacity added and $20 billion invested as shown in **Figure 8**.

Table 6. The cost of different components of LCOE of wind projects (Stehly et al., 2020).

Components	The cost of different components of LCOE		
	Cost-1 (%)	Cost-2 (%)	Cost-3 (%)
Turbine	47.3	21	17.2
Development	0.9	2.2	2.2
Project management	0.8	1.1	1.1
Substructure & foundation	2.8	13.2	19
Site access & staging	2.1	0.9	0.6
Assembly & installation	2.1	3.2	5.8
Electrical infrastructure	6.9	12.3	13
Contingency	4.1	5.1	5.1
Construction finance	1.6	3	2.9
Operation & maintenance (O&M)	31.4	34.3	29.5
Others (insurance during construction, decommissioning, plant commissioning, & lease price)	-	3.7	3.6

Note. Cost-1: Land-based wind project; Cost-2: Offshore fixed bottom wind project; & Cost-3: Floating offshore wind project

Texas installed the most wind capacity in 2021 with 3,343 MW, followed by Oklahoma, New Mexico, and Kansas; eleven states exceeded 20% wind energy penetration. According to national renewable energy laboratory, USA has potential for 10,459 GW of onshore wind power. The capacity could generate 37 Petawatt hours annually. It has also large offshore wind power potential (Elliott et al., 2011). The wind vision report mentioned, wind can be a practical source of renewable electricity in all 50 states by 2050 since it is available nationwide. It is affordable since wind generation agreements typically supply 20-year fixed pricing. It can reduce the national vulnerability to price spikes of gas and coal fuel (Zayas et al., 2015).

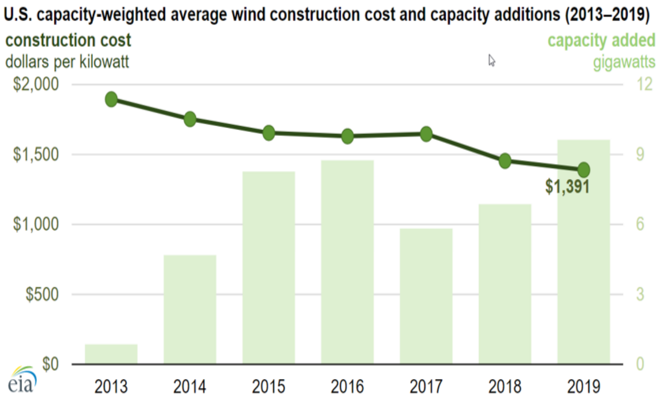

Figure 9. The average wind construction cost (Sara Hoff, 2021)

Cost and Price of Wind Energy System

The cost of a typical onshore and offshore windfarms installed capacity is about $1,000/kW and $1,600/kW, respectively. In different countries, the corresponding cost of electricity varies because of wind speed variations, locations, and distinct institutional framework (Roy, 2002).

In USA, the cost of onshore and offshore wind projects is based on estimating the levelized cost of energy (LCOE). LCOE is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. It is used to assess the cost of electricity generation, the impact of design changes of the total power plant and comparing cost of all types of generation. There are four major components of LCOE categories such as turbine capital expenditure (turbine CapEx), balance of system capital

$$LCOE = \{(CapEx \times FCR) + OpEx\} \div (AEPnet/1{,}000),$$

where *LCOE* is the levelized cost of energy measured in $/megawatt hour, *FCR* is the fixed charge rate (%) measured in MWh, *CapEx* is the capital expenditures measured in $/Kilowatt, AEP_{net} is the net average annual energy production measured in megawatt/year, and *OpEx* is operational expenditures. The LCOE method is applied to find the wind turbine costs, financing, and market conditions (Stehlyet al., 2020). **Table 6** shows the costs of various components of wind turbines, balance of systems (e.g., development, electrical infrastructure, assembly, and installation), and financial costs (e.g., insurance and construction financing).

The majority of LCOE for land-based wind project's costs are in the turbine itself while the major contributor for the offshore wind projects are the balance systems such as the fixed bottom offshore wind is 34.3% and floating offshore wind is 29.5%, respectively. In case of residential distributed wind project, the balance of system costs is the majority of the LCOE at 50% while the commercial distributed wind project cost is accounted for 51.8% by the turbine itself.

In USA, the electricity generation capacity from wind energy was accounted for 5.6% in 2012 and 8% in 2017 (USA EIA, 2021a). The onshore wind generating capacity increased by 74% from 2013 to 2019. In 2013, the average wind generator construction cost was $1895/kW which fell into $1391/kW in 2019 as shown in **Figure 9**. This growth is driven by tax incentives, utility demand, falling construction cost, and better technology (e.g., taller towers and lighter blades) (Sara Hoff, 2021).

Cost and Price Trends

The wind turbine prices increased more than $1,600/kW in 2008, which was more than half of the price from 2000-2002 ($800/kW) (Energy, 2018). After that wind turbine prices have declined steeply which is most typically in the range of $700-$900/kW (Musial et al., 2018). The installed cost of the weighted average capacity decreased by $1,000/kW from the peak in average costs in 2009 and 2010 because of lower turbine prices. Currently the sample of under construction projects suggests that the HAWT is less expensive which ranges from $1,100-$1,250/kW (Musial et al., 2018). The project construction costs depend on project size and turbine size. As the project size increases, the projects costs decrease (Energy, 2018). The project installation costs differed by regions.

Table 7. Top-9 renewable energy generation and consumption countries

Countries	Growth rate (%) (Terawatt hours)			Total consumption rate from renewable sources in 2018 (%) (million tons oil equivalent)
	Wind energy 2018	Solar energy 2018	Other renewables 2018	
USA	8.1	24.4	1.0	18.5
Canada	10.7	7.7	-1.4	1.8
China	24.1	50.7	14.0	25.6
Brazil	14.4	277.1	3.2	4.2
Japan	11.1	15.9	9.0	4.5
Italy	-1.5	-4.7	-1.0	2.7
France	15.8	10.9	6.6	1.9
India	14.6	42.8	40.9	4.9
Germany	5.6	17.2	0.7	8.4

Table 8. Cost of electricity from renewable sources (BP, 2019; Kaunda et al., 2012; WBDG, 2016a, 2016b)

Renewable energy sources	Electricity cost per kilowatt hour ($)
Wind	0.04-0.14
Solar	0.13
Biomass	0.08-0.15
Hydro	0.85
Geothermal	0.01-0.03

According to 2018 wind energy report, the interior of the country was the lowest cost-region, but the Northeast was the highest-cost region (Stehly et al., 2020). The project's operation and maintenance costs varied by project age and commercial operation date. The wind power purchase agreements have been eased by the combination of higher capacity factors, reduced installation costs, running costs, and low interest rates. The average nationwide wind power purchase agreement prices have dropped below $20/MWh from $ 57/MWh in 2017-2018 (Musial et al., 2018). Both wind and solar power purchase agreement prices are below the projected cost of burning natural gas in existing gas-fired combined cycle units with the support of federal tax incentives (Musial et al., 2018).

Comparison of Wind Energy Development with Other Renewable Energy Sources

The European Commission mentioned in their report that a considerable number of RES based projects have been developed in many areas around the world. Most of the studies have been conducted at an international level with the public opinion to understand their support for this kind of technology. The report reveals that 80% of the EU citizens support the use of solar energy, 71% of wind energy, and 65% of hydroelectric energy (Kaldellis et al., 2013). The worldwide renewable energy generation and consumption countries are shown in **Table 7**.

The data is obtained from BP statistical review of world energy (BP, 2021); 68th edition. The renewable energy generation and consumption countries are respectively China, USA, India, and Germany, etc. (BP, 2019). The wind energy is comparatively expensive than solar energy. The main cost of wind power is the turbine installation cost which can run as high as $65,000 while the average solar panel installation cost is about $8 to $9 per watt. However, based on geographical location and energy requirements both wind and solar energy are intermittent (Dunnett et al., 2022; Regen Power, 2021). Both wind and solar energy has some pros and cons. Wind turbine releases less CO_2 to the atmosphere compared to solar panels. It consumes less energy and produces more energy overall. For wind energy, once the project has been paid off, the only ongoing expenses are operation and maintenance costs. The capital cost is in between 75% and 90% of the total cost. **Table 8** shows the cost of electricity from various renewable sources.

Comparison of Wind Energy with Other Renewable Energy Sources

Wind energy can be produced at day or night, but it is an unpredictable energy source. Solar supplies more predictable energy, but it cannot be produced at night or ineffective in cloudy regions. Hydro power is a more predictable energy source but its reliance on stored water in reservoirs. Biomass energy is caused by organic compounds like animal waste. Wind farms can generate power on a massive scale. Solar farms can also generate power on a massive scale but not all roofs have the right angle to collect the suns energy. Since hydro power is producing in water, it can cause a loss of habitat. It can also often cause of upstream flooding which can destroy wildlife habitat, scenic areas, and prime farming land. However, producing electricity from biomass is not economically practical. Wind turbines produce more electricity than solar panels. Solar panels generate significantly less electricity than wind turbines. Hydro power is the intermittent energy supply of wind and solar. Wind turbines convert the kinetic energy in the wind into mechanical power. A generator converts the mechanical power into electricity. Solar energy converted electricity in two ways such as photovoltaic and solar cells which change sun lights directly into electricity Hydro power uses turbines and generators to convert the kinetic energy into electricity. Biomass energy could be used directly.

RENEWABLE ENERGY POLICIES

Energy policies are the actions that the government take to address issues of energy development which includes energy conversion, distribution, and use. The purpose of energy policy is to access the new energy at affordable prices, improved energy security and independence, greater sustainability, and economic growth. The features of energy policies include legislation, international treaties, incentives to investment, the country's targeted energy generation, guidelines for energy conservation, strategies to stimulate the energy industry, taxation, and other public policy techniques as well as the focus on new (usually renewable) energy sources. The main purpose of this strategies is to reduce the dependency on fossil fuels, the environmental impacts of the energy sector, and to encourage the new development (Saidur et al., 2010). Besides these, there are two most popular policy tools such as FIT and the renewable portfolio standard. There is some debates abouts their effectiveness and expectation to make a choice between them. The effectiveness refers to the extent to which the policy can meet quantitative aims. In most cases, renewable energy policies simply aim to increase the share of renewable energy generation (Gan et al., 2007).

Federal, State, and Local Government Policies

In USA, the energy policy is decided by federal tax incentives, state renewable portfolio standard, and local public entity (Byers et al., 2018). The deregulation of the electricity market in USA has facilitated power generation from renewable sources in late 1970s (Gan et al., 2007). The government and the regulatory agencies at federal, state, and local levels have adopted policies to support the renewable sources such as wind, solar, and biomass etc. The federal government has supplied funding for research and development (R&D), demonstration grants, and other financial incentives. The federal funding for R&D, and other programs are inadequate compared to other fuel and energy sources. USA Department of Wind Energy Program receives about $50 million funding annually which is well below than other resources (Saidur et al., 2010). The financial incentives include tax deductions and credits to produce the electricity from wind, solar, geothermal, and closed-loop biomass facilities. The federal renewable energy production incentives are also called production tax credit which supplies incentives only for new qualifying renewable energy facilities to produce electricity. The payments are adjusted for the entire output of a qualifying facility during the first 10 years of its operation (Menz, 2005).

Feed-in-Tariff

An FIT is another policy mechanism which is designed to support the development of RESs by offering a long-term contract to renewable energy producers. It helps the renewable energy technologies to compete with the conventional energy sources (e.g., natural gas, coal, oil, petroleum, nuclear, etc.) that are highly subsidized (Rickerson et al., 2008). A strong benefit of FITs is to ensure the market certainty. It aids to promote the green electricity production through mobilizing the funds via surcharges on electric power in general. It is meaningful both in terms of political communication and from a public finance perspective which can be both transparent and flexible. It is proven effective in Germany, particularly in mobilizing producers/investors' interest and participation (Gan et al., 2007). The FITs have supplied a stable profitable market for wind generators in Denmark, Sweden, Germany, Spain, China, and Japan (Saidur et al., 2010). In USA, the FITs are comparatively new and used to a limited extent. These programs are mandated to verifying degrees in a limited number of states. In recent years, Virginia put a spotlight on FITs, which is used to encourage deployment of renewable electricity technologies. In USA, FITs are included solar PV, but the other countries particularly Germany and Denmark were initially tested and developed by supporting wind energy (USA EIA, 2013).

State Rules and Regulations

In USA, the state rules and regulations include system benefits charge (15 states), renewable portfolio standard (15 states), green power purchase requirements (16 states), construction design standards (12 states), mandatory green power option for customers (five states), and net-metering rules (38 states). Among these rules and regulations, construction and design standards and green power buying requirements have been implemented in the local levels rather than statewide (Menz, 2005).

Voluntary Green Electricity Schemes

Voluntary green electricity schemes allow the customers a certain amount of electricity purchases to be from renewable energy resources. This is also called green pricing programs. It is mostly found in some European countries such as Austria, Germany, Finland, Ireland, Netherlands, Sweden, Switzerland, and UK. It is also found in USA, Canada, Japan, and Australia (Gan et al., 2007). These measures are recently adopted in many states in USA, and they are still in implementation.

Quota System and Tradable Green Certificates

Renewable energy quota and tradable green certificate are an incentive system, where the government sets the percentage or an amount of energy that comes from the renewable sources. In this system, the cost is determined by the marketplace, but a certain amount of energy is mandated from renewable sources. This system is more proper in developed economies than developing economies. It is an alternative to the other policy mechanisms such as renewable investment subsidies, FITs, and fiscal benefit (Anciaux, 2019).

BARRIERS OF THE WIND ENERGY

A small number of energies is generated from the renewable sources, especially in developing countries through a remarkable promotion and commitments by various nations. Several common barriers are the reason for this scenario that control the dissemination of the renewable energy (Heal, 2020). The clustering barriers are, as follows:

1. regulatory barriers (e.g., regulatory frameworks, policies, and institutional abilities),
2. economic barriers (e.g., costs, financial aspects, or market distortion),
3. technical barriers (e.g., technological constraints, infrastructure),
4. social barriers (e.g., consumer behavior, education, societal attitudes, cultural habits, and moral issues) (Heal, 2020), and
5. environmental barriers (e.g., visual intrusion, disturbance to local ecology) (Kaygusuz, 2004).

Regulatory Barriers

The lack of regulatory framework is a strong challenge in terms of incentives and secure investment structures for private investments (Heal, 2020). The absence of regulatory barriers includes national policies, inadequate incentives, administrative obstruction, and lack of standards and certifications. They have intercepted the expansion of renewable energy market. Lack of effective policies create confusion among the various departments over the implementation of the subsidies (Zhang et al., 2014). The administrative obstruction such as planning delays and restrictions are creating unnecessary obstacles and increase the timeline for the development phase of the project (Zhang et al., 2014).

Economic Barriers

For wind power market development, the influencing factors of economic and financial barriers are high initial cost, lack of financial institutes, lack of investors, and fewer subsidies compared to traditional fuel. Also, the global energy investment in 2016 from fossil fuel was 55% compared with 16% of renewable energy (Seetharaman et al., 2019). The most serious disadvantage of wind farm is the initial cost of setting up. In many countries throughout the world, the govt. is supplying subsidies for this reason (Letcher, 2017).

Technological Barriers

There are several technical barriers to the extensive deployment of wind energy market. The technical barriers for wind energy are inefficient knowledge of operation, maintenance, inadequate R&D initiatives, limited availability of infrastructure, and technical complexities (e.g., storage and lack of standards). The technical complexities prevent the wind energy in achieving large scale commercialization (Seetharaman et al., 2019). Wind turbines and their accompanying generators are considered as modern technology and often unknown to most general engineers. It can be a problem in the rural areas if the turbine malfunctions (Letcher, 2017).

Social Barriers

In multiple locations wind energy is still broadly unknown. Consumers have insufficient information about its overall benefits. The public is not aware of the benefits of wind energy due to lack of successful demonstration, educational efforts, and public information campaign (Diógenes et al., 2020). Sometimes the project proposal face obstacles from individual citizens, political leaders, grassroots organizations, national interest groups, and in some cases, even environmental groups. In most cases, public goes against the concept of wind technology because of landscape impact, environmental degradation, and lack of consultation among the local communities (Seetharaman et al., 2019). In USA, the development of wind energy is terribly slow in many regions of south and central America due to lack of sufficient wind energy policy and low electricity prices. Larger wind turbines such as 300 kW are difficult to install due to infrastructural limitations for larger equipment (e.g., cranes) (Kaygusuz, 2004).

Environmental Barriers

The operation or construction of wind farms cause disturbance to local ecology, particularly to bird life. Such disturbances include direct collision with blades or tower and disturbance to bird breeding (Benner et al., 1993). The most annoying aspect of wind turbines beside visual is noise and is more of a problem at night (Shepherd et al., 2011). Studies confirmed that large wind farms could affect on the atmospheric circulation and exchange of gases, depending on the wind farm location (Mann and Teilmann, 2013). Sophisticated modeling generated strong pointers that tall and turbine and large-scale wind farms may have significant impacts on the climate on the long run (Abbasi & Tabassum-Abbasi, 2016).

DISCUSSION

This section will be contextualized and evaluate the level of economic development and the stage of wind energy diffusion. Distinctively, the discussion will explore the wind projects strategy to overcome the challenges such as inefficiencies, securing financing, increasing social awareness, improving the technological infrastructure, and reducing the regulatory barriers to summarize the response strategies of wind energy development.

Assessment of Wind Resources

The wind resource assessment is a process of estimating how much fuel will be available for a wind power plant over the course of its useful life. By using this process, the wind farm can determine how much energy the plant will produce, and how much it will earn (Brower, 2012). It is a crucial factor for development, siting, and operation of a wind plant. The wind plants can supply clean, renewable power to business and homeowners at lower cost with more accurate prediction, measurement of wind speed, and direction. It helps to understand the wind farms to integrate the enormous quantities of wind energy into system operations as well as develop capabilities (Center for Sustainable Systems, 2020).

Secure Financing

One of the most common barriers of wind power development market is the high capital investment cost, lack of market procedures, financial mechanisms, and power grid infrastructure (Blanco, 2009; Dabiri et al., 2015). In USA, the main incentives used at the federal level to promote the development of renewable energies are production tax credit. This traditional production tax credit system is short term, which is usually issued for three years (deCastro et al., 2019).

Increase Social/Community Awareness

The lack of social or community level acceptance is recognized as a powerful barrier to the diffusion of wind, as discussed. The main cause of objection is based on social/ community concern about visual impacts, noise, light and shadow flicker, and effects on wildlife. The environmental issues only represented obstacles to wind energy when household consumers or local communities near wind farms (Diógenes et al., 2020). With this respect, people need to increase the awareness of benefit from green power. There are some alternatives frameworks that have been suggested to overcome some of these constraints such as social license to operate, create favorable or positive response by providing proper education, successful demonstration, and public information campaign (Zimmerman and Reames, 2021). The recent detailed and accurate information about wind energy development parameters (e.g., cost, technology, energy markets, infrastructure, socio-environmental impacts) is essential to promote wind energy (Diógenes et al., 2020). The new wind development can be situated offshore in shallow waters near the coast. In offshore, there are many areas where the wind resources are greater and more constant. The noise and visual intrusion can be avoided to install wind farms in offshore as well (Kaygusuz, 2004).

Improve the Technological Infrastructure

The main struggles related with the success of wind projects are associated with the issues of transmission, and proximity to pre-existing transmission infrastructure (Zimmerman and Reames, 2021). The intermittent nature of wind energy leads to volatile and less controllable electricity supply. The integration of wind energy on grids turning out to be challenging and challenging task because of its potentially harmful effects on power quality, grid scheduling plans, grid stability, and supply-demand adequacy. These harmful effects may be exacerbated by the presence of weak grid infrastructures, featuring congestion or transmission losses. These issues are occurred in the developing countries. The main concern is to improve the technological infrastructure with the turbine technology regarding to its quality and reliability (Diógenes et al., 2020).

Reduce the Regulatory Barriers

It creates problem in realizing financial incentives, tax on wind energy, unstable macroeconomic environment, restricted access to technology, and lack of involvement of stakeholders in decision making. It is especially important to highlight the design and implementation of support instruments to promote wind energy diffusion (Diógenes et al., 2020). In USA, the national policy about the renewable energy is not clear. Most of the policy implementation occurs at the state and local levels. In this case, a stable national policy can affect on market behavior through the greater confidence and time perspective of investors (Gan et al., 2007).

CONCLUSION

This paper presents a systematic review of wind power market in USA. The development of renewable energy is a key part of the international commitment to fight against the climate change. The wind energy is a part of a change in electricity generation away from larger and more centralized plant towards more dispersed local electricity generation. It increases the diversity of energy sources by growing as a major source of renewable energy across the globe. Though, there are still some barriers and obstacles in the development of wind energy, but the solutions are also being found. The findings from the literature have confirmed that USA has high adequacy for the implementation of the large-scale onshore wind farm. The water level in the coastal area is very deep which suggests exploring modern technology such as floating offshore wind platforms.

In USA, the wind farms are considered decentralized because of its spread implementation over the territory, and isolated in a small-medium complexes which are distant from the large electricity demand concentration. The literate survey says that the potentiality of wind energy for USA is very encouraging. There is a possibility to achieve best wind energy expansion if political commitment is established through the improvement of financial support instruments, ameliorating the technological efforts, and integrating grid reinforcements by the decentralized way of generating electricity.

The important findings of this review paper are, as follows:

1. The possibility of wind energy harnessing in USA is adequate. The potentiality of generating electricity estimated at 10,459 GW in onshore.
2. The size of wind turbines is becoming larger. The average size of wind turbines was installed in 1998 at 600 kW as compared to 30 kW in the mid-1970s.
3. The average construction cost of wind generator is being declined. The cost of construction fell into $1391/kW from $1895/kW in 2019. This growth is driven by tax incentives, utility demand, the reduction of construction cost, and better technology (e.g., taller towers and lighter blades).
4. The environmental impacts of wind turbines are limited. The problems are causing with noise and visibility and increasing public resistance against the installation of new turbines in densely populated countries. The solution of these issues is to increase the awareness of the benefits of wind energy, successful demonstration, educational efforts, and public information campaign.
5. It is especially important to have a stable political commitment towards renewable energies. It is the key for the existence of support instrument for the development of wind farms. Effective government policies will encourage the wind energy producer to generate more electricity because of the commitment of financial incentives, tax credit for wind energy, and involvement of stakeholders in decision making.

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