

# Wind energy state of the art: present and future technology advancements<sup>★</sup>

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**Abstract.** Renewables today are the first-choice option for a modern power system. Wind and solar are now competitive with conventional sources and commanded a high percentage of investments in renewable power. The cost of wind turbines has fallen by nearly 1/3rd since 2009 and that of solar photovoltaic (PV) modules by 80%. The number of countries that held auctions to deploy renewables has increased (from 6 in 2005 to 67 countries in 2017) with a very large increase in global investment. Global cumulative installed wind power capacity had more than 645 GW by the first quarter of 2019. The paper reviews the recent developments in wind energy conversion systems technology and discusses future expectations. Offshore wind turbines are the most possible technology for future utilization and of this, floating wind turbines are to dominate with larger scales could reach three times the present introduced scales. This is to provide more than 20% of the global demand in 2030. The paper presents several case studies for each case and highlights the technological aspects that support each development. The most important design advancements are also discussed with a forecast of the future design expectation that will affect the wind power generation program.

## 1 Introduction

Renewables nowadays is the first choice to be considered as alternative energy when power systems need to be upgraded and developed. 90% of those renewables are in the form of solar and wind. Investments in these two sources have been sharply increasing and competitive with conventional sources of electricity. Wind energy systems' cost has been continuously. This has been reflected in the cost of electricity. Climate change associated consequences have been imposing high pressure on Governments to start looking for alternatives and sustainable energy developments reducing the carbon footprint and emission. In response, there has been a significant increase in the number of auctions held for these systems, from 6 in 2005 to more than 67 in 2017 [1]. Renewable energy investment has reached more than USD 289 billion of which USD 134.1 billion for wind energy. This has exceeded the investment in fossil fuel [2]. Worldwide renewable jobs have considerably increased and reached more than 11 million people in 2018. China was the largest followed by

the EU, Brazil, the US, and India, as illustrated in Figure 1 which shows the number of jobs offered by renewable energy implementation reached to more than 11 Million jobs in 2018 [3].

Wind power installations sharply increased in recent years. The development and advancements in wind power generation systems were at high levels and shown worldwide interest. Figure 2 shows the global cumulative installed wind power capacity (MW) [4,5].

Reference [4] found that the accumulative installed wind power capacity reached 599 GW in 2018, and this has been increased by 7 % in 2019 to reach 645 GW [5].

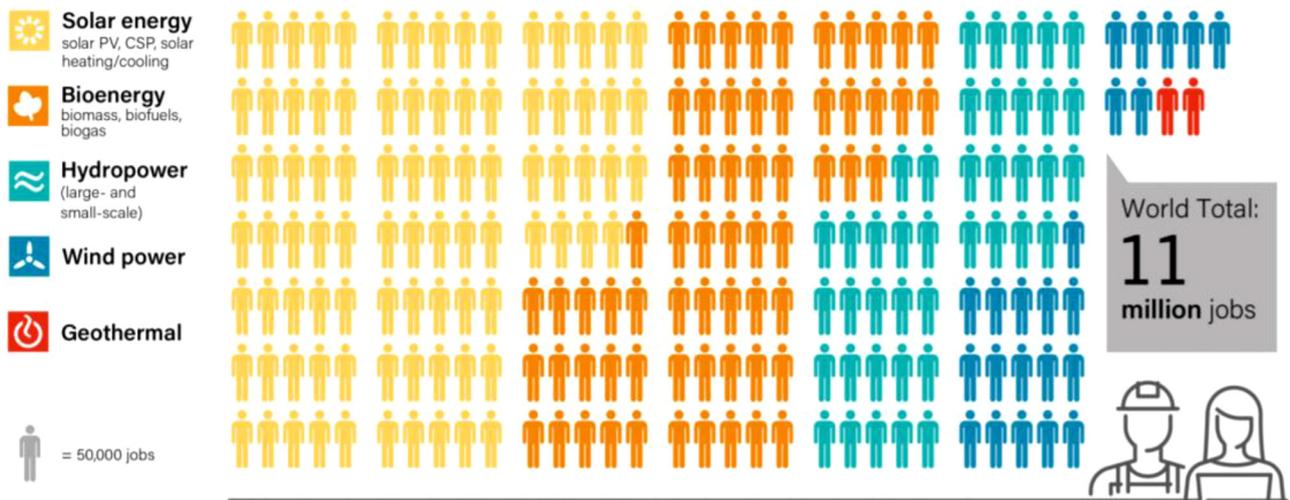
Wind energy associated system technology development needs to be sustainable in order to support climate mitigation, economic benefits, and energy security [6]. Wind energy has a global technical potential five times the current global energy production (i.e. forty times the global electricity demand with the best-assumed scenario [7]).

In this paper, it is aimed to the present status of renewables and specifically wind energy developments and to overlook the future of wind energy with the latest technology advancements. The research is to present the most promising technology i.e. the floating wind system as the future practical system for implementations.

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### Jobs in Renewable Energy



REN21 RENEWABLES 2019 GLOBAL STATUS REPORT

Source: IRENA.

Fig. 1. Jobs in renewable energy 2018 [3].

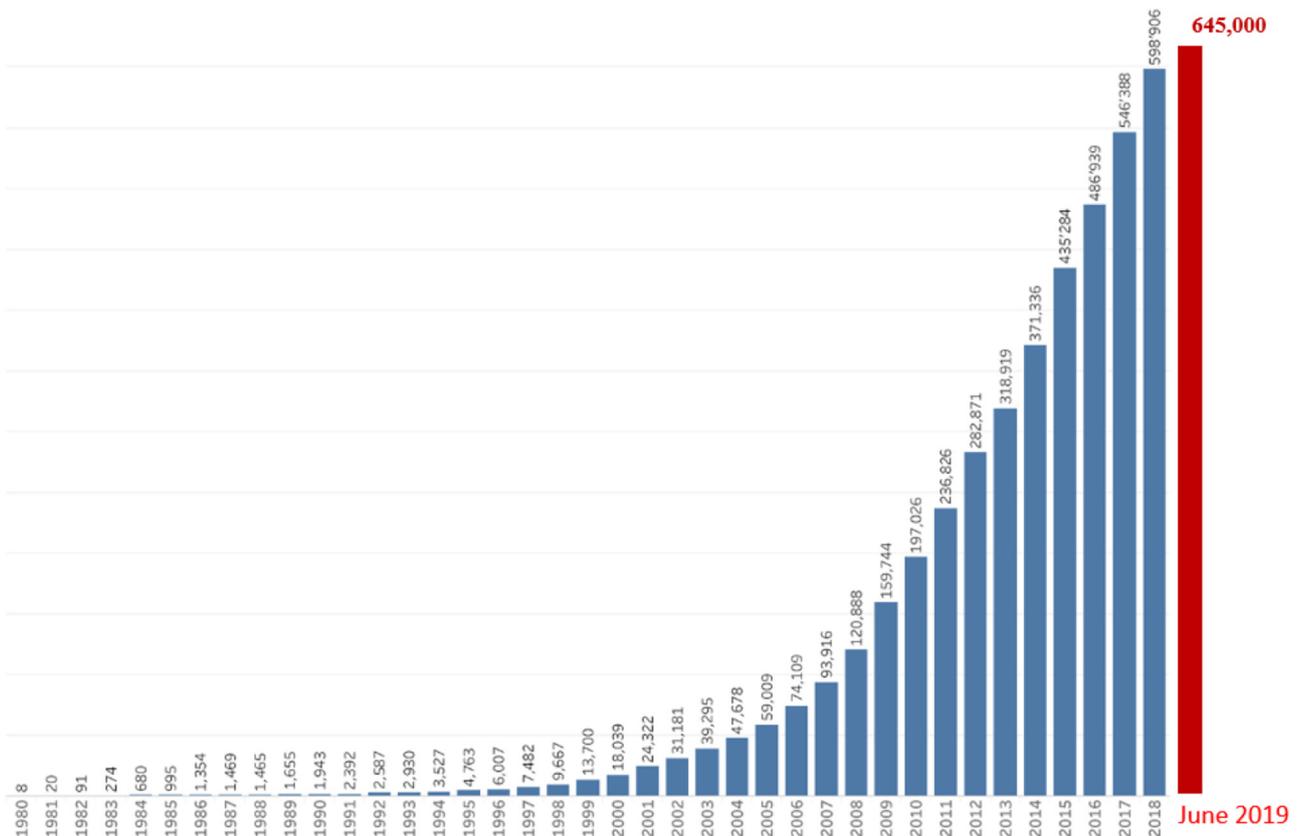


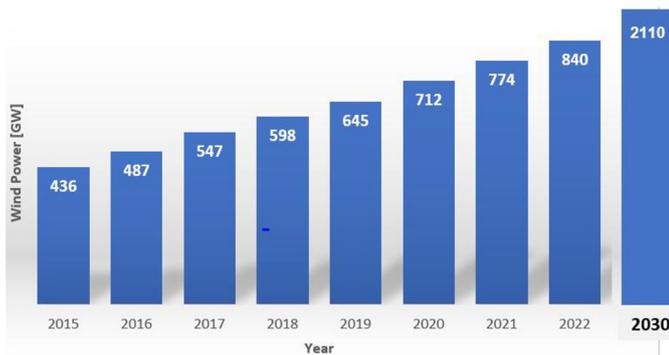
Fig. 2. Global cumulative installed wind power capacity (MW) [4,5].

## 2 Wind power to dominate power sector growth

Different scenarios were outlined by the Global Wind Energy Council to suggest that wind energy systems could provide 20% of the global demand for electricity by

2030 [8]. As the Paris Agreement targets state a completely decarbonised electricity supply before 2050, wind energy will have a major role on this target.

2110 GW generated capacity could be reached by 2030 which would be equivalent to 20% of the Global needs. It is expected to create more than 2.4 million jobs with 3.3



**Fig. 3.** Expected cumulative generated capacity in 2030 In GW [8].

billion tonnes of CO<sub>2</sub> emissions a year. An investment which reaches about €200 billion is expected within ten years [8]. This is to be supported by many key factors such as the dramatic decrease in the wind energy systems price which brightens the feasibility of the deployment of such systems which make it economically competitive. In addition, the recent advancement in those technologies and the developments in the smart grids could well be the new battery storage achievements. Therefore, an increased movement towards growing the market for electric vehicles as well as public transport increasing the future demand for electricity. Wind energy power systems are more likely able to supply this electricity demand, Figure 3 shows the predicted and expected cumulative generated capacity in 2030 [8].

### 3 Global wind energy systems' market

Global wind energy systems' market in comparison with other renewable energy sources can be seen in Figure 4 [5].

It is clear from Figure 4 that, a continuous steep cost reduction curve. Solar and wind power generation costs are significantly lower than nuclear, gas and coal plants. 2018 showed a considerable increasing number of contracts in both sources is noticed. Special support from international lenders has recently intensified for the developing countries.

### 4 Wind roadmap targets

Wind roadmap target is presented in Figure 5 which shows the wind regional wind electricity production to 2050 (TWh) [9].

It is clear from Figure 5 that the Wind is expected to have the potential to provide 20% of global electricity production in 2050. In this respect the Global Wind Energy Council (GWEC) [10], envisions 5.8 TW of wind by 2050. GWEC anticipated that China would remain the world's largest market with 1789 GW of wind power by 2050, North America – including the US, Canada and Mexico – combining to have 919 GW and OECD Europe could have

703 GW of wind by 2050. In addition, Latin America predicted to generate (481 GW) and India (452 GW) [10]. Two scenarios (Moderate and Advanced) for the regional breakdown presented in Figure 6.

## 5 World electricity demand scenarios 2050

Many scenarios and plans in different countries suggested that in the future up to 40% wind penetration can be safely assumed by the year 2050 ([11], pp. 42). In this respect, electricity consumption will not increase to as high a value as 74000 TWh/yr but remains at a low of 40000 TWh/yr. The expected reasons are ([11], pp. 42):

- significantly increased energy efficiency,
- climate change,
- significant variations in trends due to social, political and economic reasons,
- technological development and other competing technologies, etc.

Scenarios such as LOW, LIKELY, or HIGH could well be considered that wind power generation could vary from the highest expected point to a rather low point. Table 1 summarises the World Electricity Demand scenarios 2050 ([11], pp. 42).

## 6 Renewable energy and energy efficiency can provide over 90% of the reduction in energy-related CO<sub>2</sub> emissions

A reference case mentioned by the International Renewable Energy Agency (IRENA) analysis has expected a slight increase in energy-related CO<sub>2</sub> emissions until 2040 then slightly dipping by 2050 to today's level, see Figure 7 [12]. IRENA's analysis has concluded that renewable energy and energy efficiency, coupled with deep electrification of end-uses, can provide over 90% of the reduction in energy-related CO<sub>2</sub> Emissions and the remainder would be achieved by fossil fuel switching.

## 7 Future of wind energy in Europe

Figure 8 shows a total of wind power generation installed up to 2018 was 178.8GW [13]. This has increased to 183.7GW by 2019 overtaken the Natural Gas.

The combined installations of onshore and offshore wind capacity in Europe was the same as in 2018 but onshore was down. Table 2 shows the wind energy installed capacity by country in 2019, which shows a total of 4.9GW [14].

Scenarios were published by EWEA (European Wind Energy Association) [15], for the future of wind energy installed and implemented technology in Europe and emphasised that wind energy's potential in 2030 will depend to a large extent on recent policy developments in the major EU climate and energy priorities. The EWEA's position on EU energy and climate priorities are related to [15]:

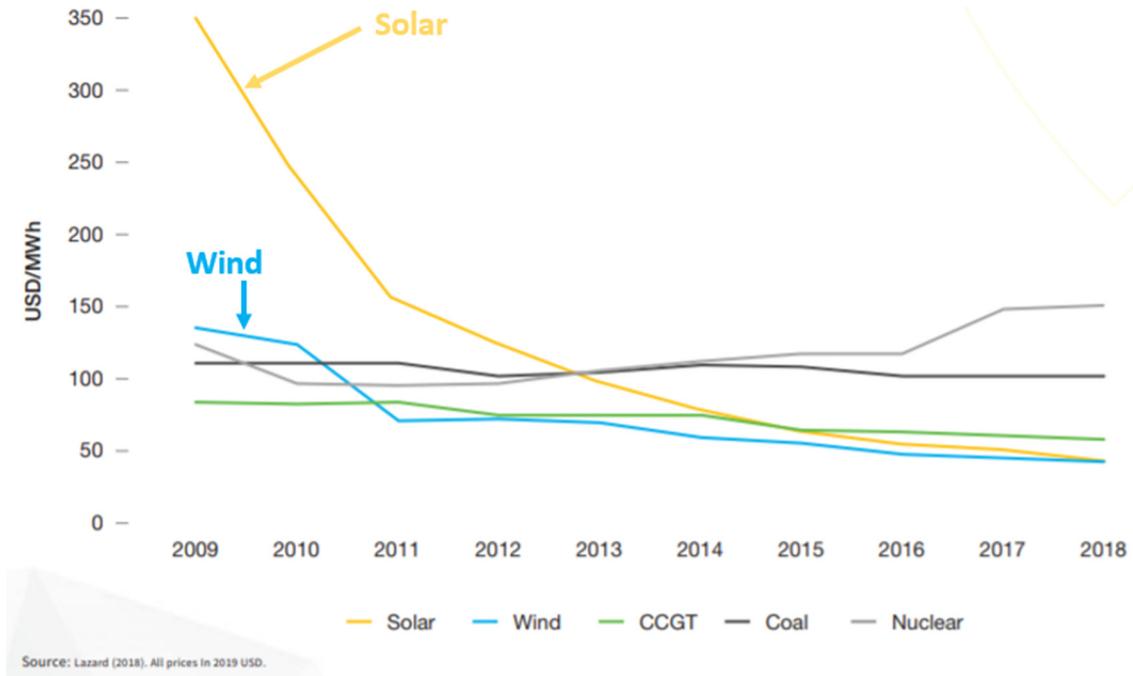


Fig. 4. Wind electricity generation cost in comparison with other power sources 2009–2018 [5].

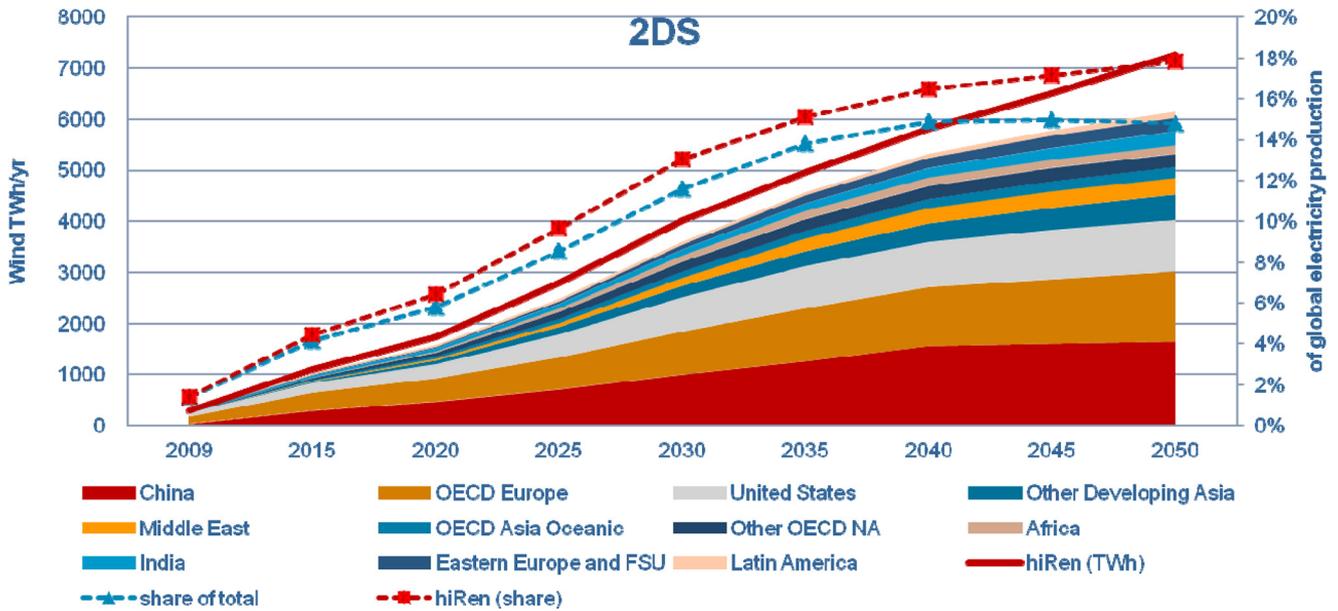


Fig. 5. Wind power deployment to 2050 in the Roadmap vision [9].

Table 1. World electricity demand scenarios 2050 [11].

Low (40,000 TWh)	Worldwide electricity demand (TWh/yr)			Wind
	Likely (57,000 TWh)	16,000	High (74,000 TWh)	
8000	12,000	16,000	Low = 20%	
11,400	17,100	22,800	Likely = 30%	
14,800	22,200	29600	High = 40%	
All figures in TWh.				

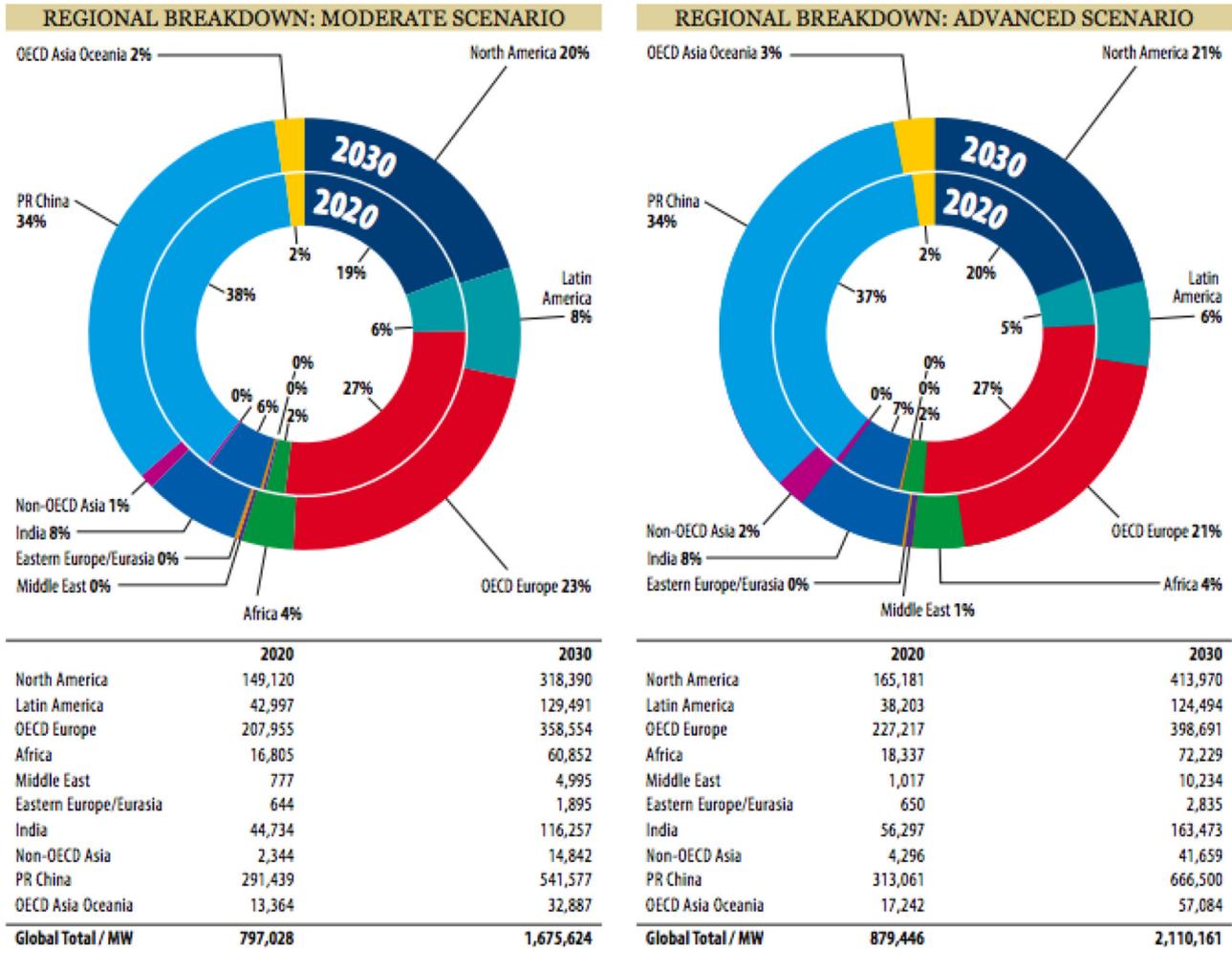


Fig. 6. Moderate and advanced wind energy regional break down scenarios [10].

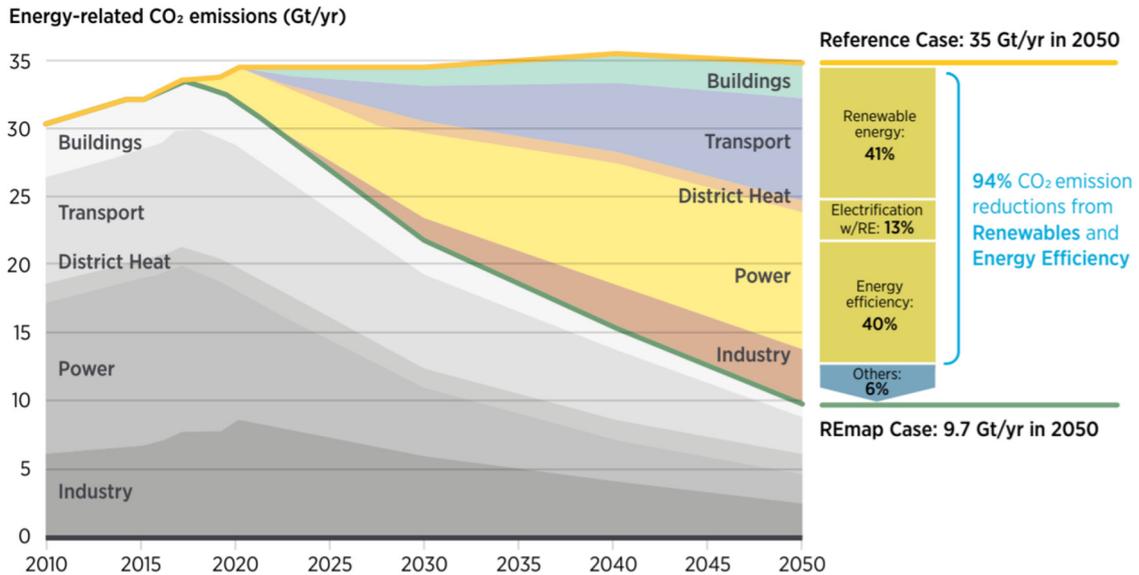
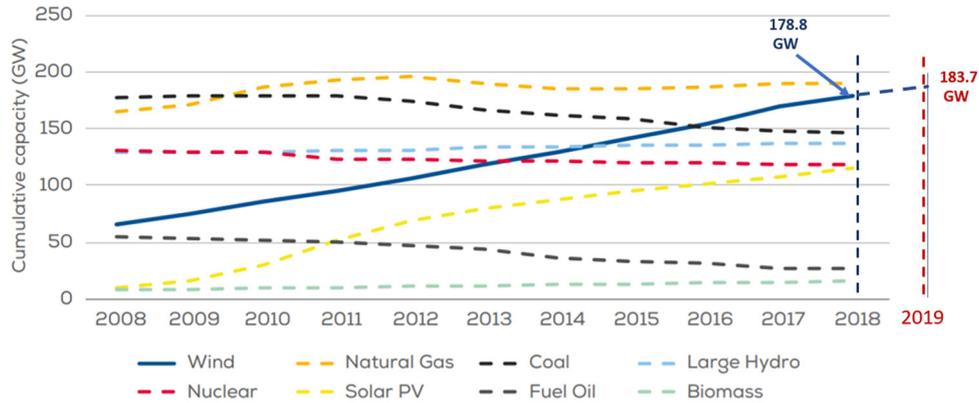


Fig. 7. Annual energy-related CO<sub>2</sub> emissions and reductions, 2015–2050 (Gt/yr) [12].



Source: WindEurope

Fig. 8. Total power generation capacity in the European Union 2008–2018 [13].

Table 2. Installed wind power in Europe 2019 [14].

Onshore	MW
France	523
Sweden	459
Germany	287
Italy	286
Ukraine	262
Turkey	229
Greece	201
UK	187
Spain	148
Netherlands	83
Belgium	72
Portugal	57
Ireland	51
Russia	50
Bosnia and Herzegovina	36
Poland	17
Austria	16
Croatia	10
Denmark	6
<b>Total</b>	<b>2,979</b>
Offshore	MW
UK	931
Denmark	374
Belgium	370
Germany	252
<b>Total</b>	<b>1,927</b>

Total Onshore and Offshore = 4.9 GW

– Governance: The European Commission should make sure that the Member States deliver the 27% target post-2020 period.

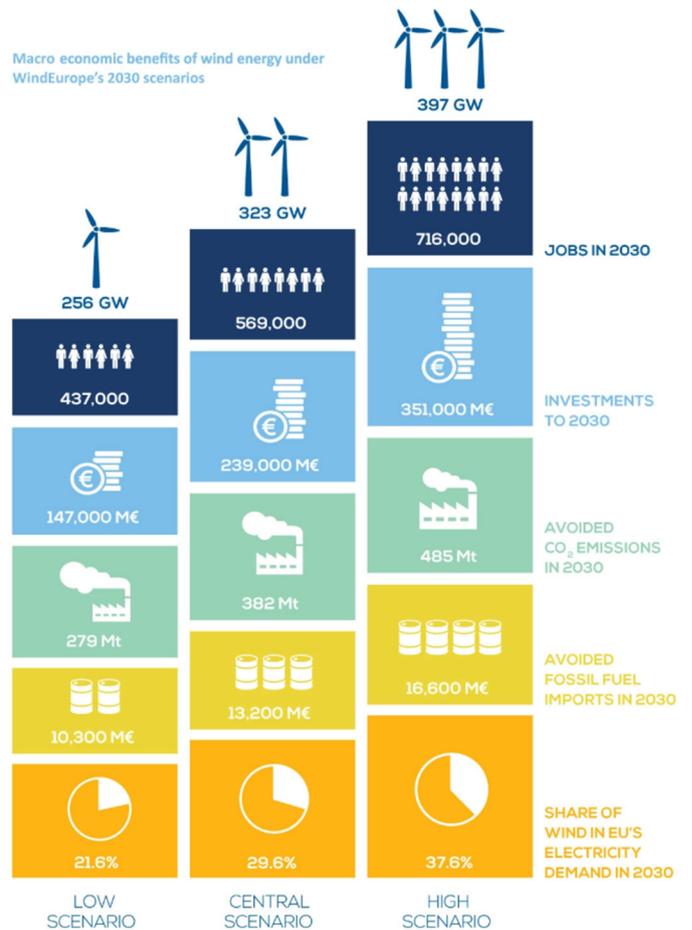
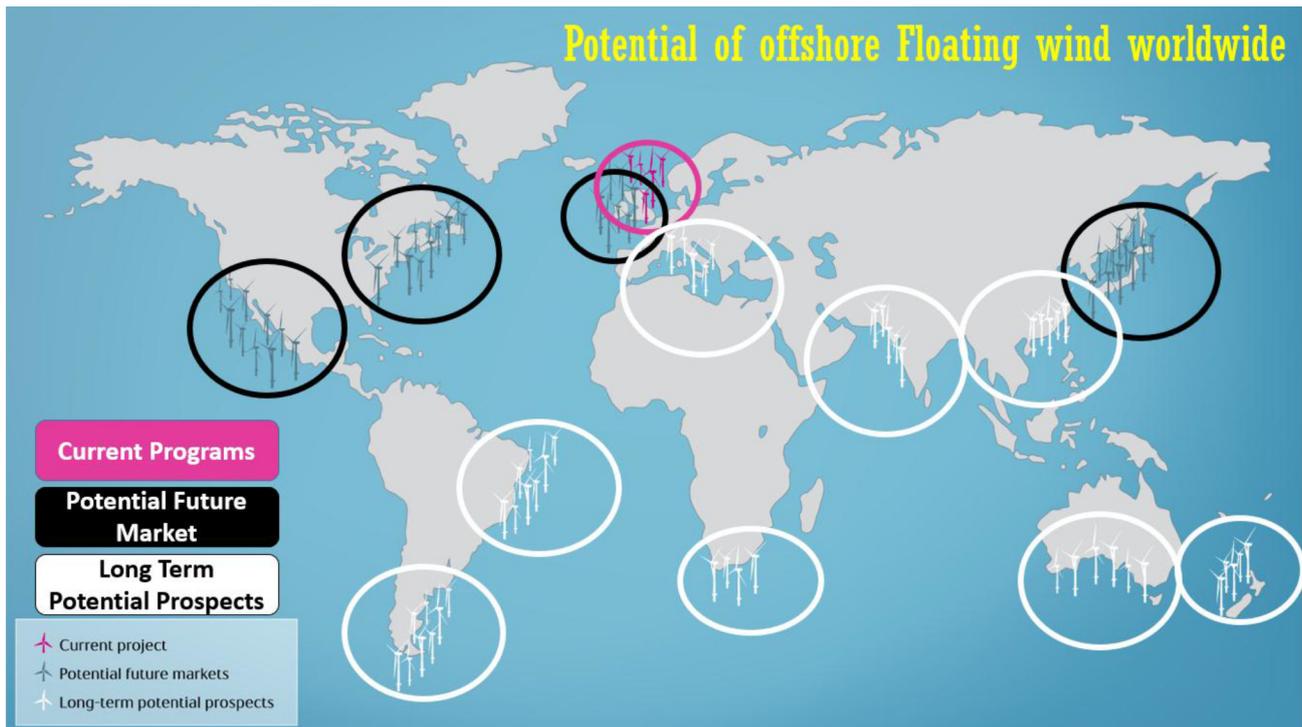


Fig. 9. Macro economic benefits of wind energy [16].

- Market design: In order to drive larger renewable energies penetration price signals should drive a well-functioning power market.
- Renewable Energy Directive: Renewables Directive will be responsible for the post-2020 to deliver the binding EU renewable energy target for 2030.

**Table 3.** EWEA 2030 scenarios: capacity installed, power generation and percentage Of EU electricity demand met.

	Installations (GW)			Generation (TWh)			EU electricity demand Met by wind energy (%)		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
Low scenario	206.3	44.6	250.9	440.2	164.5	604.5	13.8%	5.2%	19%
Central scenario	253.6	66.	320.1	533.1	244.5	777.7	16.7%	7.7%	24.4%
High scenario	294.0	98.1	392.1	627.	360.8	988.3	19.7%	11.3%	31%

**Fig. 10.** Shows map shows the vast potential of offshore wind worldwide [18].

– Emission Trading System (ETS): Provide an incentive for investments in renewable energies by reforming the Emission Trading System providing free allocation.

Capacity installed, power generation and percentage of European electricity demand met by wind energy is expected to be 24% as shown in Table 3 [15].

## 8 Europe 2030 economic benefits scenarios of wind energy

Other scenarios were worked out for the future of wind energy utilization in Europe [16]. The central scenario Figure 9, shows that the total installed capacity by 2030 will be 323GW and it will provide 569,000 jobs with 239,000 m€ investments. Avoided CO<sub>2</sub> emissions are estimated to be around 382Mt and avoided fossil fuel is 13,200 M€ and share of the electricity demand 24–29%.

## 9 Floating wind technology

Offshore wind technology is receiving more interest from investors and in specifically the floating wind turbines for several reasons. The cost of offshore wind falling steeply and will keep doing so. Another reason is that higher and steadier wind speeds are available in deeper waters. The potential of offshore floating wind worldwide is shown in Figure 10 [17]. The floating wind turbines are utility-scale and cost-effective energy sources that experience lower offshore wind turbulence enjoying longer farm life ~25–30 years. In addition, connection to the electric grid by subsea AC or HVDC cables becomes cheaper, easier and can easily utilize the experience of oil industry floating technology which has made floating turbine installation more efficient. Floating wind technology has a reduced near the coast and onshore wind farms related problems such as the eyesore on the landscape, poor wind speeds onshore, noise pollution, visual impact and species such as birds and bats may also be affected by wind turbines.

## 10 Conclusions

It is concluded from this research that with appropriate investment in renewables, the world can achieve 100% clean energy production by 2050. With the cost of wind turbines has fallen by nearly 1/3rd since 2009, it is believed that the wind has the potential to provide 20% of global electricity production in 2030, creating 2.4 million new jobs and reducing CO<sub>2</sub> emissions by more than 3.3 billion tonnes per year. Worldwide wind capacity reached 645GW in 2019. If the right investment and the anticipated proper implementation of a renewable energy system, renewable energy and energy efficiency can provide over 90% of the reduction in energy-related CO<sub>2</sub> emissions. Offshore wind turbines are the vision of our future technology and the floating wind turbine will have major implications.

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