Environmental Energy and Economic Research 2019 3(1): 1-9
DOI 10.22097/eeer.2019.164295.1064

Worldwide Development of Wind Energy and CO2 Emission Reduction

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Received: 11 April 2018 /Accepted: 20 December 2018

Abstract
One of the most serious issues in the global society is reducing CO_2 emissions which is caused by human activities; therefore, recently the importance of exploiting energy from clean resources is taken into consideration. In this regard, the researchers investigated the impact of renewable energy utilization to achieve the low carbon economy and concluded that it can significantly reduce the CO_2 emissions of transportation and industry sectors. Wind power offers a sustainable option in the pursuit of renewable energies. In this research, the development of wind energy in the world and leading countries is investigated. It is found that in the year 2017, the utilization of wind resources has prevented at least 600 and up to 1100 million tones CO_2 emissions. Also, if the current rate of wind energy development continues, up to 3100 million tones CO_2 will be avoided in the year 2030. Eventually economic analyses illustrated that utilization of wind energy in 2030 can reduce up to 316 billion dollars in global energy costs and more than 450 billion cubic meters natural gas equivalent of fossil fuels resources.

Keywords: Wind energy, CO_2 emission, Fossil fuels, Forecasting

Introduction

The increase in population and economic growth have led to an increase in energy consumption; so that in the last 30 years, energy demand has risen significantly. In this regard, electricity production has risen from 15400 TWh in 2000, to 25500 TWh in 2017 and it is projected to reach more than 45000 TWH a year by 2030 (BP, 2017). Considering these issues, along with reserve to production of fossil fuels, identifies the necessity of exploiting more energy from renewable resources. Therefore, the global society has turned the spotlight on the utilization of renewable energy due to the exhaustibility of fossil fuels, greenhouse gas emissions and the global warming issues.

The global warming which is the result of fossil fuels combustion, has become one of the most important human concerns and there have been several worldwide meetings to discuss this issue. Most of the scientists believe that industrial activities are the main reason of the CO_2 emissions and recent climate changes. According to the investigations, by the end of 21st century, the global average temperature will raise between 3.7 and 4.8 degrees Celsius; therefore, greenhouse gas emissions should be extremely controlled during this period

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(Pachauri et al., 2014). In December 2015, the United Nations Framework Convention on Climate Change (UNFCCC) presented the international climate change agreement AT COP21 which could both reduce greenhouse gas emissions and maintain global economic growth (Den Elzen et al., 2016; Iyer et al., 2015).

The scientist investigated the impact of renewable energy utilization to achieve the low carbon economy and concluded that it can significantly reduce the GHG emissions of transportation and industry sectors (Chunark et al., 2017). Renewables will have the fastest growth in the electricity sector, providing almost 30% of power demand in 2023, up from 24% in 2017 (IEA, 2018). Recently, in more than 30 countries, about 20% of the energy supply has been produced by renewables and the total global investment in the renewable sector has been over 214 billion US dollars (Ellabban et al., 2014).

Wind power offers a sustainable option in the pursuit of renewable energies. Wind energy refers to the technology that converts the air motion into mechanical energy usually for electricity production. Wind energy conversion devices can be broadly categorized into two types according to their axis alignment; including horizontal and vertical axis wind turbines. They can be located either in-land (onshore) or in bodies of water (offshore). The advantages of wind energy are more apparent than the disadvantages, which explains why it’s one of the fastest-growing energy sources in the world. The main advantages are low maintenance cost, enormous potential and placement of wind harvesting facilities. Also the two major disadvantages of wind power include initial cost and unpredictability of generated energy.

There are many worldwide studies on renewables, especially wind energy, development and its impacts on greenhouse gases emissions and air pollution reduction. Crawford et al. (2009) estimated that a 3MW utility-scale wind turbine would avoid nearly 123000 tones greenhouse gas emissions over 20 years operation. Ashraf (2006) estimated the CO_2 mitigation potential of renewable energy in comparison with pollution caused by coal-fired thermal power plants. The result of their work showed that, Wind has more CO_2 mitigation potential as compared to small hydro, biomass and solar photovoltaic system in India.

Martinez et al. (2009) found that the environmental pollution from wind turbine manufacturing, usage and decommissioning is offset by its operation in less than one year. They also estimated that a 2MW wind turbine produces 34 times more energy than is used in its life-cycle. Liu et al. (2011) focused on the various factors of CO_2 reduction, especially wind energy in china. They also analyzed the pollutant and the cost of CO_2 reduction in China. Panwar et al. (2011) reviewed the different types and applications of renewable energy and investigated the impact of them on the reduction of GHG. Yousefi et al. (2017) assessed the impact of Ground Source Heat Pump (GSHP) utilization for air pollution reduction in Tehran, Iran. Their calculation indicated that the implementation of national plan to extend the share of GSHP systems, leads to a reduction of 9429 tones CO_2.

Zhang et al. (2016) presented the role of wind energy technology development in electricity generating, costs and energy safety. They introduced wind energy as a carbon free source and emphasized on economically and environmental benefits of it in electricity generating. Chunark et al. (2017) investigated the potential of greenhouse gas emission reduction by the use of renewable energy in Thailand's Intended Nationally Determined Contributions (INDCs) at the Paris agreement. They also assessed the economic impacts from GHG emission reduction.

Also, Kusumadewi et al. (2017) focused on CO_2 mitigation potential in Thailand based on the Power Development Plan (PDP) and Alternative Energy Development Plan (AEDP). In this context, they investigated the role of different renewable energy including wind energy in reducing the amount of CO_2 emissions. In a similar research in Thailand, Winyuchakrit et al. (2016) investigated the greenhouse gas mitigation through renewable energy especially wind resources by using the Asia-Pacific Integrated Model/ Extended Snap Shot model. Delarue et al. (2009) presented a simulation model for wind energy and then determined its impacts on cost of electricity generation and CO_2 emissions. They verified their model by applying it to a case study in Belgium.

In this article, an updated report of wind energy development in the world and leading countries is presented. After that, the maximum and minimum potential of wind energy utilization to reduce CO_2 emissions is estimated from 2002 to 2017 and forecasted by the year 2030. Finally, economic analysis was done to assess the impact of wind power utilization on the conservation of fossil fuel resources and carbon cost reduction in 2030.

Methods and Materials

In this section first, the development of wind energy in the world is discussed. Then, to calculate the amount of CO_2 emission reduction, four different capacity factors for wind farms and the annual electricity generation is considered. Finally, the economic analysis of CO_2 mitigation considering the carbon price and the cost of energy supply by fossil fuels is done.

Wind energy development in the world

Harnessing wind energy can be done almost anywhere in the world; whether or not this is financially feasible is another question. Wind energy is now successfully competing across the globe; building new industries and leading the way towards a clean energy future. More than 52 GW of wind power was installed across the world in 2017, reaching the total cumulative capacity to 540 GW (GWEC, 2017). Wind capacity is expected to grow by 350 GW in the next five years and reach almost 900 GW by 2023 in the main case of the IEA Renewables 2018 forecast (IEA, 2018). Also, Wind power penetration levels continue to increase, This sector currently provides around 4.5% of the world's generation capacity, up from 3.5% in 2012 (IEA, 2017). The global annual and cumulative installed wind capacity by the end of 2017 and its projection to 2030 has presented in figure 1. From a regional point of view, Asia is the largest wind market, representing more than 40 percent of world installed capacity; followed by Europe (over 34%), North America (20%) and Latin America & Caribbean (3%) (IEA, 2018). Share of different regions in utilization of wind energy is shown in Figure 2.

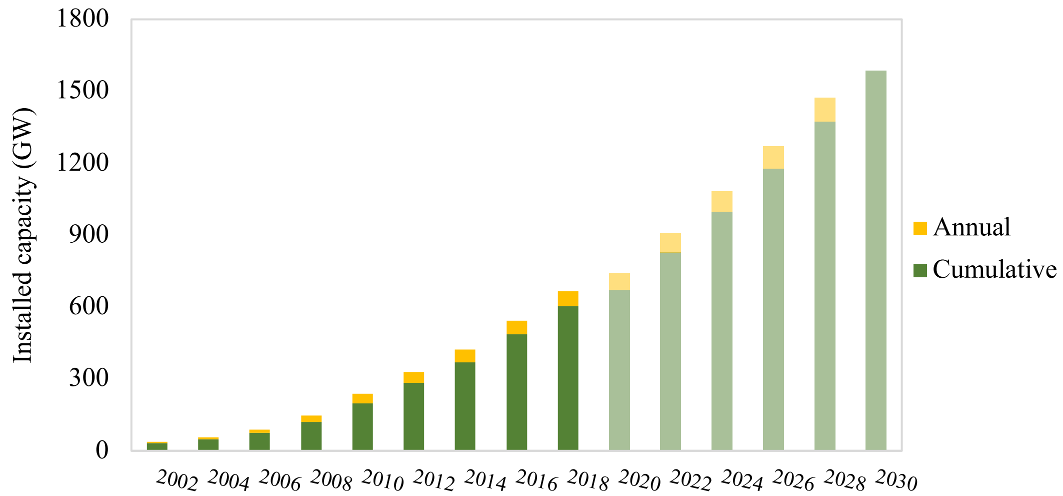

Figure 1. The projection of global cumulative and annual wind installed capacity by 2030

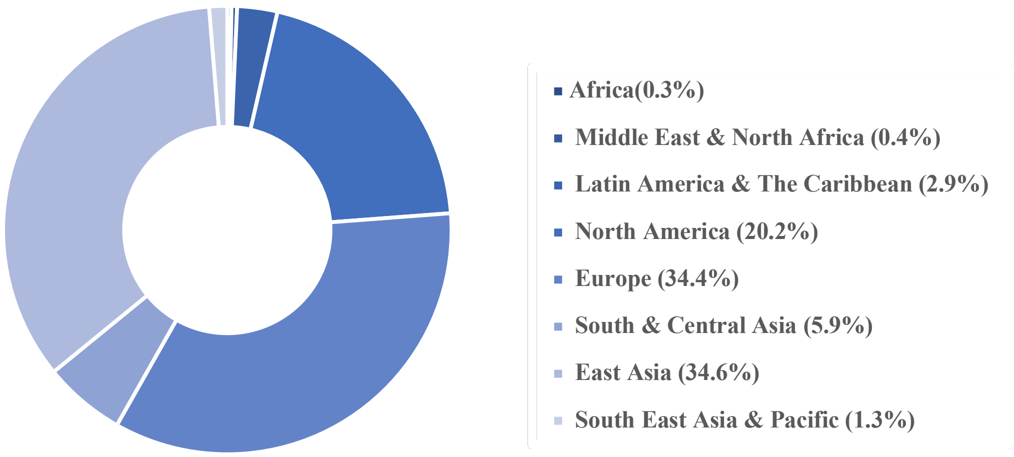

Figure 2. Wind installed capacity by region (IEA, 2018)

Nowadays most countries have the capacity of wind energy utilization, and its manufacturing technology is developing in different regions. By the end of 2017, more than 90 countries had seen commercial wind power activity, and almost 30 countries had more than 1GW in operation (IEA, 2018). In this regard, three leading countries are China, United States and Germany. China has ranked first in cumulative installed capacity with the total capacity of 188 GW by the end of 2017 (GWEC, 2017). In terms of annual installations, China maintained its leadership position and added 19.7 GW of new capacity in 2017 (GWEC, 2017).

In this country, in the regions with the best wind regimes, wind energy is one of the most competitive source of energy in terms of financial feasibility (Liu et al., 2011). It can be seen that China has a solid foundation for the development of wind energy and The Chinese government has identified wind energy as a promising and sustainable energy to alter the traditional fuels. Likewise, the United States surpassed the Germany and has become the second largest country in wind energy development. As the end of 2017, the U.S. installed more than 89 GW wind capacity (GWEC, 2017). U.S. was also second in terms of the annual installation, with 7017 MW of new capacity added in 2017 (GWEC, 2017).

Wind energy is the largest source of renewable electric capacity in this country; and to stay competitive in this sector, the energy department of U.S. invests in wind research and development projects to advance technology innovations (Oteri et al., 2018). Germany has led the field in installing wind power capacity in Europe by adding 6500MW of new wind capacity and reaching the total installed capacity to over 56GW (GWEC, 2017). This was largely due to the end of the country feed-in tariff regime and the entry of feed-in premiums with auctions (IEA, 2018). The German wind industry expects to see new installations of 3.5GW in 2018 (IEA, 2018).

Overall, there is a lot of confidence in the wind power market going forward, as the technology continues to improve, prices continue to go down, renewable power to reduce emissions, the air become cleaner and new industries get stronger.

Impact of wind energy on CO_2 emissions reduction

Wind power is almost a no-pollution resource and a solution to reduce CO_2 emissions which caused by fossil fuels combustion. It should be noted that in the life-cycle of all renewable resources including wind turbines, some pollutants produces. The objective of life-cycle assessment (LCA) is to describe and evaluate the overall environmental impacts, including CO_2 emissions of utilizing renewable resources; by analyzing all stages of the entire process from raw materials supply, production, transport and energy generation to recycling and disposal stages.

The life cycle emissions of wind power depend on the amount of material and work needed to construct the wind turbines. The results of International Atomic Energy Agency researches show that the life cycle emissions of a wind turbine varies between 7 and 22 tones CO_2 equivalent per GWh of electricity generated, depending on construction technology (WEC, 2004). The life-cycle emissions of different electricity generation systems is presented in Figure 3.

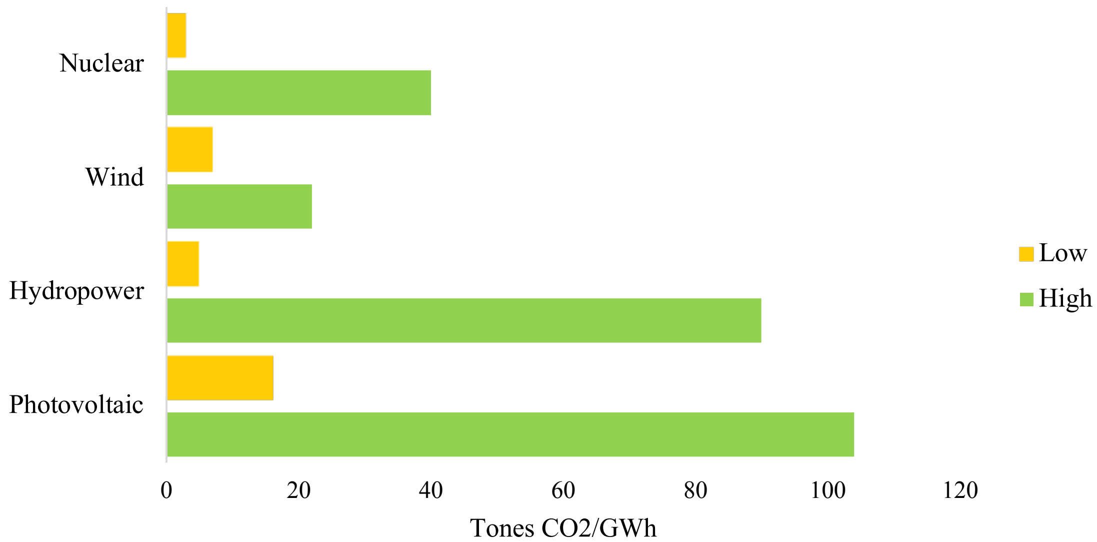

Figure 3. CO_2 emissions from renewable and nuclear electricity production systems (Tones carbon dioxide per GWh of electricity generated) (*WEC*, 2004)

Nonetheless, the CO_2 emission avoidance of wind energy is much more than its life-cycle emission. CO_2 emission reduction potential of wind energy depends on the energy diversification of each region. In fact, where fossil fuels have greater share in electricity generation system, there is more potential to reduce CO_2 emission by utilization of wind energy resources and carbon emission avoidance factor would be higher. But in regions with high share of renewable and nuclear energy, the CO_2 emission factor would be lower. Totally according to the energy mix of the world, it is estimated that every GWh of electricity generated from wind resources, will avoid 640 tones CO_2 emission in the world (Saidur et al., 2011). So, emission reductions can be calculated using carbon emission factor 640 tones CO2/GWh and Formula 1 (Saidur et al., 2011); where A is the installed capacity of the wind energy in GW, C is the capacity factor and 8760 shows the number of hours in a year.

$$CO_2 = A \times C \times 8760 \times 640 \quad (1)$$

Wind farms typically operate at 20 to 35 percent of their capacity, depending on local wind conditions; so in this article four different estimated CO_2 reduction is calculated according to four capacity factor and equation 1. Table 1 illustrates how much CO_2 has been avoided by using wind energy in 2001.

Table 1. Estimated CO_2 reduction from wind farms in 2002

Capacity factor (%)	Estimated Annual Electricity Output (GWh)	Estimated annual CO_2 emissions reduction (million tons)
20	54500	34.9
25	68000	43.6
30	82000	52.3
35	95260	61

By applying this process, estimated CO_2 emissions reduction could be calculated by the end of 2017. Cumulative maximum and minimum CO_2 emissions reduction potential is calculated from 2002 to 2017 and forecasted using linear regression method up to 2030 in Figure 4. The results show that by the end of 2017, utilization of wind resources has avoided at least 600 and at most 1100 million tones CO_2 emissions.

It can be expected that with the current trend of wind energy development by the year 2030, wind energy will reduce CO_2 emissions up to 2100 million tones. Also the effect of wind energy development on CO_2 emissions in the world is shown in Figure 5. In fact, Figure 5 illustrates the amount of CO_2 emissions in the presence or absence of wind energy in the energy system.

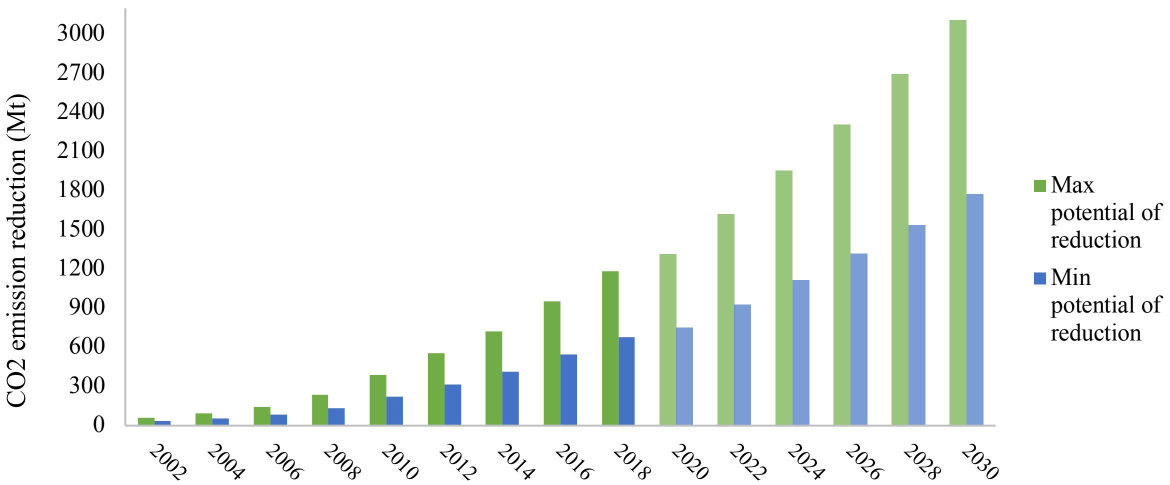

Figure 4. CO_2 emissions mitigation potential of wind energy resources in the world

Figure 5. Effect of wind energy development on CO2 emissions mitigation in the world

Economic analysis

The world is moving forward with regulations to limit CO_2 emissions and its consequences, but a regulation is not yet finalized. A price on carbon emissions helps shift the burden for the damage back to those who are responsible for this issue. The carbon price gives an economic signal and polluters decide whether to discontinue their polluting activity, reduce emissions, or continue polluting and pay for it. For example, if the CO_2 emissions price of producing electricity from coal were to be factored into electricity bills, 2-7 eurocents per kWh would have to be added to the current price of electricity in the majority of EU Member States (EU, 2003).

Current carbon price initiatives only cover 15 percent of global emissions, and 85 percent of these emissions are priced at under $10 per ton. But it is expected, most of the global emissions be subjected to carbon pricing, by 2030. Based on analyses, Low, Mid and High case forecasts for CO_2 prices in 2030 is developed. The Low case forecasts a CO2 price that begins in 2020 at $15 per ton, and increases to $25 in 2030 (Luckow et al., 2016). The Mid case forecasts a CO2 price that begins in 2020 at $20 per ton, and increases to $35 in 2030 (Luckow et al., 2016).

The High case forecasts a CO2 price that begins in 2020 at $25 per ton, and increases to approximately $53 in 2030 (Luckow et al., 2016). Therefore, it is possible to calculate the capital saving by utilizing wind power plants, according to CO_2 mitigation potential and carbon pricing. In Table 2, considering the maximum and minimum CO_2 emissions reduction potential of wind energy, also the low, mid and high case forecast for carbon prices, the cost reduction using carbon price initiatives is calculated for 2030.

Table 2. Effect of global wind energy utilization on carbon cost reduction in 2030

Utilization potential	Carbon price forecasting	Cost reduction (million US dollar)
Max	High case	164744
	Mid case	108793
	Low case	77710
Min	High case	94185
	Mid case	62197
	Low case	44427

On the other hand, the utilization of wind energy preserves the fossil fuel resources, including natural gas. The amount of saved natural gas can be calculated according to the produced energy from wind resources and the heat value of natural gas. Studies also show that gas prices will reach to 326 dollars per 1,000 cubic meters in 2030 (Huppmann et al., 2009). Eventually, by multiplying the amount of saved natural gas and forecasted price of natural gas in 2030, the amount of retained capital will be calculated in this year. Considering maximum and minimum utilization potential of wind energy resources, amount and value of saved natural gas in 2030 is calculated in Table 3.

Table 3. Effect of global wind energy utilization on fossil fuel consumption cost reduction in 2030

Utilization potential	Saved natural gas (million cubic meter)	Value (million dollars)
Max	469337	152982
Min	268322	87473

Utilization of wind energy sources can lead to a reduction in energy generation costs through two main ways; fossil fuel consumption and carbon cost reduction. According to the explanations and calculations made in this section, it was found that, there is a 44 up to 164 billion dollars potential of reducing carbon emission cost in the world. Also, there is a possibility to reduce fossil fuel consumption costs at least 87 and up to 152 billion dollars in the year 2030. Therefore, it can be expected that by the end of 2030, with the current trend of wind energy development, in addition to maintaining more than 450 billion cubic meters of natural gas equivalent, up to 316 billion dollars in global energy costs will be reduced.

Conclusion

Exhaustibility of fossil fuels, greenhouse gas emissions and the global warming issues have led to an increase in the share of renewable energy in the electricity generation. Wind power offers a sustainable option in the pursuit of renewable energies. Wind energy is a sort of renewable energy which is utilized to generate clean and sustainable power. Wind turbines generate electricity without directly emitting air pollutants that are known to affect the climate and human health. The main objective of this study was to investigate the effect of development of wind energy on reducing CO_2 gas emissions. CO_2 has the greatest share in the enhancing greenhouse effect which caused by human activities. Therefore, reducing this component can have a significant impact on the greenhouse effect and its consequences. The overall results of this study is discussed here:

- According to the latest statistics of the Global Wind Energy Council, total installations in 2017 were at least 52 GW and cumulative capacity increased to 11 percent, to around 539 GW. By the end of 2017, more than 90 countries had seen commercial wind power activity and China, United States and Germany are pioneer in wind power utilization.
- The amount of CO_2 which produced in life cycle of wind turbines is compared with other electricity production systems.
- The amount of CO_2 mitigation avoidance due to wind energy utilization was calculated and its value in the year 2030 was predicted. The results showed that by the end of 2017, the utilization of wind resources has prevented at least 604 and up to 1057 million tones CO_2 emissions. Also, if the current rate of wind energy development continues, up to 3100 million tones CO_2 will be avoided in the year 2030.
- Economic analyses show that development of wind energy can reduce up to 316 billion dollars in global energy costs; and save more than 450 billion cubic meters of natural gas equivalent of fossil fuels resources in 2030.

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