

# Renewable Energy: A Solution to Hazardous Emissions

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**Abstract:** The problem of energy security, increasing prices of energy, the aspect of environmental pollution and depletion of the known fuel reserves in future have created a scope for utilization of renewable resources. Increasing prices of fossil fuels and costs associated with emissions may affect the economy of a country severely. Similarly, fossil fuels although produce useful energy, are responsible for production of harmful emissions like CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub> etc. These dangerous emissions are an acute threat to human health on our planet. The obvious choice available is to use renewable energy, which can play a critical role to mitigate these emissions. In this article, hazardous environmental effect of fossil fuels is discussed. The status of existing renewable energy technologies especially wind and solar energy and their future growth trend is presented in this article. In this article a focused literature review on research articles discussing the environmental impact of replacement of fossil fuel energy technologies with renewable technologies, with goals to prove that if fossil fuel energy is replaced by renewable technologies can be a solution to hazardous emissions. Last part of the article provides directions for renewable energy policies of a country, which could help to increase the renewable energy mix in the traditional energy production.

**Keywords:** Renewable Energy, Emissions, Greenhouse Gases, Mercury Emissions, Wind Energy, Solar Energy

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## 1. Introduction

Technological and environmental developments in today's world are causing a steep rise in energy demand. World economy is increasing at a rate of 3.3% /year and energy demand is increasing at 3.6%/year since the last 30 years. International energy outlook 2009 indicates the increase of energy demand from 472 quadrillion Btu in 2006 to 552 quadrillion Btu in 2015 and to 678 quadrillion Btu in 2030. The historical increasing energy demand and the projected demand is shown in Fig. 1 [1].

Various industrial processes and conventional power generation plants are releasing hazardous gasses to contaminate the environment.

The rapid growth of human activities in the recent past has resulted in a dangerous level of greenhouse gases (GHG) in the atmosphere. Control of these GHG emissions is necessary to avoid the negative consequences on climate. Fossil fuels are the main source of energy in today's world but at the same time they are the main source of CO<sub>2</sub> emissions as well [2]. According to IPCC study, The level of GHG emissions has to be controlled in order to bound the temperature increase to 2°C above pre industrial level [3].

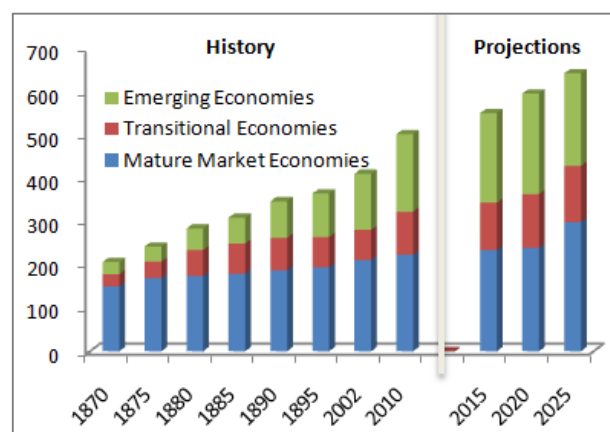


Fig. 1. World energy demand growth.

Negative impact of fossil fuel on our environment and other associated problems of fossil fuels have forced many countries to shift to environmental friendly renewable alternatives that could sustain the rapid growth in energy demand. Environmental issues has received highest attentions in many countries. One of the example is the 20-20-20 target of European Union (EU). According to that target of EU, the share of renewable energy must be

increased by 20%, GHG emissions cut by 20% and the use of primary energy decreased by 20% [4].

## 2. Emissions from Conventional Power Plants

**Carbon Dioxide Emissions:** Carbon dioxide is one of the main source of climate change. About 90% of the total  $CO_2$  emissions are coming from the energy sector and accounts for 75% of the global GHG emissions in the developed countries [5]. Power plants and refineries account for about 50% of these emissions. Carbon is emitted as  $CO_2$  during fossil fuel combustion, some carbon is emitted as carbon monoxide (CO), methane ( $CH_4$ ) or non-methane volatile organic compound (NMVOCs). For  $CO_2$ , emission factors majorly depend on the carbon contents of the fuel rather than combustion conditions.  $CO_2$  emissions can be accurately estimated from the amount of combusted fuel in the combustion process [5]. South Korea is generating 154.7million tons of carbon per year, out of which  $CO_2$  emission is 136.9 million tonnes which is 85% of total GHG emissions. Coal combustion is generating huge quantity of  $CO_2$  per unit heat energy as compared to other fossil fuels [6].

**Mercury Emissions from Coal Fired Power Plants:** Mercury (Hg) is one of the most dangerous emission to the atmosphere, land and water. Global environmental emissions of mercury estimation in 2005 was 1930 tonnes from all anthropogenic resources. Coal combustion processes are one of the major source of mercury emission to the atmosphere [7,8]. Mercury emissions from coal combustion processes accounts for around 45% of global anthropogenic mercury emissions [9]. Mercury emissions from the coal depends upon the amount of coal combusted. Although, the quantity of mercury content in the coal is not very high, the Hg emitted from the coal combustion process is globally quite significant mainly because of the huge amount of coal used in coal fired power plants [9]. Mercury concentration in coal mainly depends on the type of coal and its origin [10].

Poland is ranked Europe's fourth highest anthropogenic mercury emitting country in 2005 [10]. According to World Coal Institute (2008), Poland was ranked the top country using coal for the generation of electricity. In 2006, 93% of the electricity was generated from the burning of brown and hard coal. In 2008, Poland's power generation mix indicates that 33% of the electricity was produced by brown coal and 62% electricity was generated by hard coal [10].

South Africa is the world's second highest mercury emitting country [11]. The primary source of mercury emissions is the coal combustion process in the coal-fired power plants. South Africa is the world's third highest coal producing country. About 64% of the primary energy supply in the country is coming from coal. Coal-fired power plants are responsible for 61% of the total consumption of coal in the country. These power plants are producing more than 90% of country's electricity. Mercury content in the South African

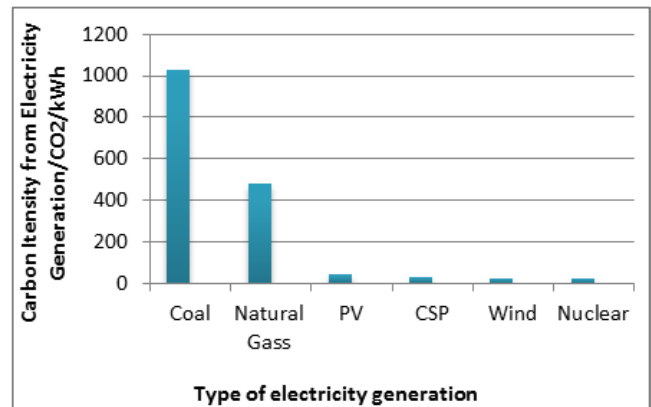
coal is 0.2mm and estimates of mercury emissions in the country were based on the quantity of coal combusted in these power plants, which was about 112.3Mt/year [12]. Mercury emissions in South Africa are 50 tonnes Hg/year. Mercury emissions from coal-fired power plants in various countries are presented in Table 1[12].

**Table 1.** Mercury emissions from coal fired power plants.

Country	Emission Tones Hg/years	Fraction of total electricity generation from coal (Ratio)
Canada	1.3	0.27
China	72.86	0.47
Mexico	1.6	0.78
Poland	20.6	0.96
Russia	16	0.68
USA	42.6	0.7
South Africa	50.0	0.92

Results of a recent study presented in [13] show that 49% of lakes in USA contain fish with concentration of mercury above the permitted safe limit. Conventional electricity production plants emit 50-1000 times more mercury (Hg) to the environment than solar power plants, i.e. about 15g Hg/GWh from coal as compared to around 0.1g Hg/Gwh from solar equipment [14, 15].

## 3. Emissions Mitigation via Renewable Energy



**Fig. 2.** CO<sub>2</sub> emissions from different electricity generation methods.

The environmental impact of any technology for energy can be characterized from its hazardous carbon emissions intensity, which is the measured quantity of mercury emissions, carbon dioxide or carbon dioxide equivalent per unit of energy generation. Here carbon dioxide equivalent means any non-CO<sub>2</sub> greenhouse emissions like nitrous oxide, methane etc. which are the result of carbon rich fossil fuels combustion for various human activities. On the other hand, renewable technologies like solar and wind energy will produce very little or no emissions at the operation stage. These technologies can release some emissions at the manufacturing stage. CO<sub>2</sub> emissions per Kwh from different

renewable and conventional power generation methods are shown in Fig. 2 [16]. It can be seen in the figure that renewable technologies produce very small amount of  $CO_2$  emission as compared to carbon rich conventional fossil fuel technologies.

The amount of emissions mitigation depends on the type of energy resource displaced by the renewable technologies, the amount of convention energy generation resource replaced and the type and amount of energy used during the manufacturing stage, installation phase and during operation of these renewable energy technologies.

## 4. Solar and Wind Energy; A solution to Environmental Emissions

Global warming effects and other dangerous climate changes associated with fossil fuels are being consider as a serious threat to human health [17, 18]. There is a growing concern about the increasing energy demand and its environment contamination problem. In order to address these concerns, the global community is taking major steps to include alternative source of energy. Renewable resources especially, solar and wind energy, will play a significant role to meet the future energy demand and to reduce the environmental pollution caused by the conventional fossil fuel resources.

### 4.1. Solar Energy

In one second, some  $1.73 \times 10^{17} J$  of energy falls on earth in term of solar radiations [19]. Almost 4 million Hexa-Joules ( $1EJ = 10^{18}$ ) of energy reaches the surface of earth from sun during a period of one year. Out of which approximately  $5 \times 10^4 EJ$  could be harvested. This harvested amount is much more than our existing primary energy needs of 533 EJ in 2010 and projected energy demand of 782 EJ I 2035 [20]. Inspire of this massive potential only 0.5% of our electricity need is being provided by solar energy [21]. Solar energy is very important for low carbon development in the developing countries. Developing countries, in general, enjoy a higher level of solar radiations [20].

#### 4.1.1. Impact on Human Health and Well-being

Solar power generation is rapidly increasing day by day. Currently world's installed capacity of solar is more than 22.9GW and is escalating at about 40%/year [13]. Table 2 depicts the impact of solar PV energy in forested area on human well-being and human health. The impact is globally very beneficial due to reduced toxics emissions resulting from the use of fossil fuels.  $NO_x$ ,  $SO_2$  and other significant pollutants are the result of conventional fossil fuel plants. About 64% of the world's greenhouse emissions are coming from fossil fuels electricity plants [12] and bulk of the remaining emissions are the result of petroleum use which can be replaced by green energy resources. These emissions are a major health hazards being faced by the humanity in today's world.

#### 4.1.2. Importance of Solar PV Energy In Terms of Emissions

Damon Turney and Vasilis Fthenakis calculated the  $CO_2$  emission per KWh of solar PV electricity for a forest region in USA [13]. The calculation were made assuming a plant life of 30 years, operating under isolation of

Table 2. Impact of solar PV on environment.

Impact category	Effect relative to traditional power	Beneficial or not beneficial
Exposure to hazardous chemicals		
Emissions of mercury	Reduces emissions	Beneficial
Emissions of cadmium	Reduces emissions	Beneficial
Emissions of other toxics	Reduces emissions	Beneficial
Emissions of particulates	Reduces emissions	Beneficial
Other Impacts		
Noise	Reduce noise	Beneficial
Recreational resources	Reduces pollution	Beneficial
Visual aesthetics	Similar to fossils	Neutral
Climate change	Reduces change	Beneficial
Land occupation	Similar to fossils	Neutral

$1700 kWh/m^2$  per day, having a module conversion efficiency of 13% and a 0.5% per year degradation rate in the module performance. The results are presented in Table 3 [13] that shows the following: (i) 0 to 9 g emissions of  $CO_2/kWh$  resulted from the loss of forest sequestration (ii) 0 to 2 g emissions of  $CO_2/kWh$  in the 10 years following deforestation (iii) 0 to 36 g emissions of  $CO_2/kWh$  due to removal of initial vegetation (iv) 16 to 40 g emissions of  $CO_2/kWh$  due to life cycle of solar system (v) 650 g  $CO_2/kWh$  avoidance from the conventional electricity generation. The results in Table 3 depicts that solar is very beneficial in terms of carbon emission and could be a very useful alternative to conventional power plants. The results presented in Table 3 are calculated for a forest region. In true deserted area, the solar power environmental impact would be much more beneficial.

Table 3. Carbon dioxide emissions saving.

	Carbon dioxide emissions (g $CO_2/Kwh$ )	
	Best case	Worst case
Loss of forest sequestration	+ 0.0	+ 8.6
Respiration of soil biomass	+ 0.0	+ 1.9
Oxidation of cut biomass	+ 0.0	+ 35.8
Other phases of the life cycle	+ 16.0	+ 40.0
Total emissions of solar	+ 16.0	+ 86.3
Fossil fuel emissions avoidance	- 850.0	- 650.0
Total including avoidance	- 834.0	- 563.7

### 4.2. Concentrated Solar Thermal Power

This technology concentrate the sunlight to heat up a fluid to very high temperature. This hot fluid can derive a heat engine or a steam turbine to produce electricity. Different

reflecting and concentrating efficient methods exists which could concentrate the sunlight by a multiplying factor of 70 times. These concentrating methods include, solar trough, solar parabolic dish, solar tower system, linear feresnal reflector. The worldwide installed capacity of concentrated solar power was 2.5GW and most of that was in USA and Spain [16]. The major advantage of CSP over PV technology is the easy storage of thermal energy as compared to PV. By stored heated fluid, the power can be generated during the off hours when no Sun energy is available. This storage advantage leads to less intermittency during the cloudy weather and enables the power system to match the energy demand. About 60% of the installed capacity of CSP in Spain can store the thermal energy in molten salt for six hours, which means the plants can generate full power for six hours using the stored solar heat. The other method of heat storage is steam storage but it is less efficient and heat storage can last under one hour [23].

**Carbon Mitigation Using CSP:** Different life cycle analyses show that carbon CO<sub>2</sub> quantity for each unit of electricity (Kwh) is 20-50 g [24]. If CSP system is integrated into the power grid than the thermal heat storage system would help to reduce the other storage components like PV.

#### 4.3. Wind Power Generation

A rapid growth of wind power generation has been observed in the last decade. About 2% of the world consumption is being provided by wind generation [18]. China is the world leading country with 44GW of installed wind capacity followed by United States with 40GW and Germany with 27GW of installed wind power generation [25]. More than 50GW of wind power generation plants are installed in the European Union region [26]. The cost of wind power generation per MWh are declining day by day thanks to the technology advancements in wind turbines, their control and wind atlases. This decreasing trend in the cost will help to increase the wind generated power share in the energy mix of the planet.

#### 4.4. Positive Impacts of Wind Power Generation

Unlike other conventional resources (gas, coal and other petroleum based fuel), wind energy is not environment pollutant. It can help to mitigate environmental pollution by replacing conventional resources. It is available in abundance and be harvested on land or oceans.

##### 4.4.1. Savings in Water Consumption

Water consumption is vital in water stressed countries like Saudi Arabia, Singapore and UAE where clean water resources are scarce. Convention power plants use huge quantity of water for cooling and condensing purposes. Water is also used for cleaning and fuel processing on coal power plant. Use renewable energy generation processes can save millions of liters water per day. The water consumption per KWh for various conventional power plants and renewable power generation methods is shown in Table 5 [18].

**Table 4.** Water consumption from various power generation technologies.

Technology	gal/kWh	l/kWh
Nuclear	0.62	2.30
Coal	0.49	1.90
Oil	0.43	1.60
Combined cycle gas	0.25	0.95
Solar	0.030	0.110
Wind	0.001	0.004

##### 4.4.2. Reduction in CO<sub>2</sub> Emissions

Normally wind turbines has no adverse effect on the environment only some amount of carbon dioxide emits during the construction and maintenance. Every electricity unit generated by wind will replace an electricity unit by conventional power plants and would save CO<sub>2</sub> emissions in the environment because it does not produce hazardous emissions like fossil fuels [27]. According to German Federal Ministry for the environment, in 2006, about 67 million tons of carbon dioxide were saved by producing electricity from renewable resources.

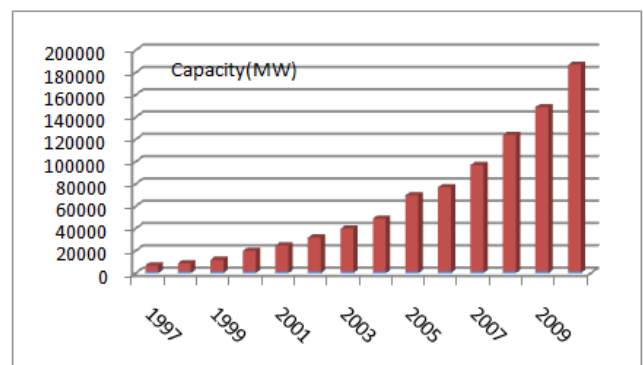
Wind power has the great capacity to mitigate the hazardous emissions on our planet. In [26], the authors calculated the emissions savings from the wind power plants in Texas. Electricity production in USA mainly depends on fossil fuel with 42% share of coal, 25% share from natural gas, 19% from nuclear, compared to 8% from hydropower, less than 1% from each of geothermal, solar and biomass, and 3% from the wind power generation.

Average emissions from a coal power plant in USA are 6 lbs/MWh of NO<sub>x</sub>, 13 lbs/MWh of SO<sub>2</sub> and 1.1 tons/MWh of CO<sub>2</sub>. Average emissions in USA resulting from natural gas plants are 1.71 lbs/MWh of NO<sub>x</sub>, 0.10 lbs/MWh of SO<sub>2</sub> and 0.57 tons/MWh of CO<sub>2</sub>. If wind power replace one MWh of USA energy mix, an emission savings of 0.79 lbs/MWh of NO<sub>x</sub>, 1.3 lbs/MWh of SO<sub>2</sub> and 0.52 tons/MWh of CO<sub>2</sub> can be achieved at ERCOT plant [26].

##### 4.4.3. Comparison of Wind Power with Other Power Generations

Wind power generation has less adverse impacts as compares to other sources of energy. A comparison of wind power with other resources is shown in Table 4 [18].

##### 4.4.4. Increasing Trend of Wind Power Generation



**Fig. 3.** Wind Capacity of the Planet.

Wind power generation does not cause air pollution like thermal power generation that depends on fossil fuel combustion (coal or natural gas). Wind turbines do not emit GHG emissions or acid rain. Due to its real tiny effect on the environment, this form of energy is considered as the true green energy. These environmental benefits are pushing the word to accelerate the installation of wind energy. The increasing trend in the wind power generation capacity is shown in Fig. 3 [28].

## 5. Policy Suggestions

Renewable energy is a true green energy, which can mitigate our environmental pollution but still it is facing some problems to become an integral part of our national grids. Electricity production from renewable resources needs to be critically analyzed. Some suggestion for renewable energy production to mitigate the negative environmental impact are presented in this section:

a) One of the hurdle to solar PV is the high generation cost. The prices of PV technologies have coming down at a great pace in the last decade or so, yet the cost of production is having issues to achieve grid parity in most of the countries. It has been seen that the developing and poor countries enjoy very good solar irradiance. The solar PV production factories can be located in these high solar irradiant countries near the load centers. The cost of Labor in these countries is very low which would help to lower the prices of PV panels.

b) One big issue with solar energy is the availability of flat land area. Normally the solar technologies PV and Concentrated Solar Power (CSP) need a lot of flat land. In the countries where flat land is not available like European countries, this problem can be addressed by installing solar PV and CSP plants in the high solar irradiant countries like Middle East with lot of flat deserts and transmitting the produced power to Europe by High Voltage DC (HVDC) transmission lines.

c) There is a need to conduct an extensive study by the countries to know the wind potential. Based on the availability of land, both On-shore and Off-shore wind forms can deployed.

d) The government can set renewable energy share targets and provide a proper financial support to achieve the set targets. In this regard, the government can provide tax incentives, relief in the duty of renewable energy technologies import and feed in tariff.

In this article, the catastrophic effect of fossil fuels on over planet are discussed. Fossil fuels although produce useful energy but they are also responsible for hazardous emissions, which are contaminating our environment. This article focused on the poisonous emissions of conventional fossil fuel power generation methods. Coal combustion is generating huge quantity of emissions per unit heat energy as compared to other fossil fuels. It has been seen that the leading countries using coal fired power plants are releasing huge amount of emissions to the environment. It has been seen that these emissions can be avoided/decreased by increasing the share of renewable energy in the energy mix. The emissions from renewable energy resources and conventional energy resources are compared and the comparison shows that renewable technologies especially wind and photovoltaic produce very little emissions over their entire life span. Today's world is taking aggressive steps to increase the renewable energy production. Further steps are required to be taken by the governments to include the alternative energy resources to replace conventional energy resources. Renewable energy policy suggestion are proposed in the last part of the article. These suggestions could help to increase the renewable energy share on our planet. The facts presented in this article by a survey of recent research of fossil fuels impact and the suggestions included regarding the policy making could be helpful for the authorities to mitigate the catastrophic impact these fossil fuel emissions.

*Table 5. Impact of wind power generation vs other power generation methods.*

Habitat impacts	Coal	Natural gas	Oil	Nuclear	Hydropower	Wind
Air and water pollution	Yes	Yes	Yes			
Global warning	yes	yes	yes			
Thermal pollution of water				yes		
Flooding of land						
Waste disposal	yes			yes	yes	
Mining and drilling	yes	yes	yes	yes		
Construction of plants	yes	yes	yes	yes	yes	yes

## References

- [1] International Energy Agency (IEA). World energy outlook. Medium term oil and gas market report.
- [2] International Energy Agency (IEA), CO<sub>2</sub> emissions from fossil fuel. Combustion
- [3] Mitigation of climate change. IPCC Fourth Assessment report by Working Group III of the International Panel on Climate Change. (hppt:// www.ipcc.ch)
- [4] Second strategic energy review. An EU energy and solidarity action plan COM (2008) 781 final
- [5] IPCC. 2006 IPCC guidelines for national greenhouse gas inventories; 2006.
- [6] Energy Information Administration. Emissions of greenhouse gases in the United States 1985-1990. DOE/EIA-1573; 1993. P. 16.

- [7] Pacyna, J.M., Pacyna, E.G., Steenhuisen, F., Wilson, S., 2003. Mapping 1995 global anthropogenic emissions of mercury. *Atmospheric Environment* 37, 109-117.
- [8] Pacyna, J.M., Pacyna, E.G., 2006. Mercury Strategy Development in the EU and UN; Current global emissions and their scenarios, MEC3 Third International Expert's Workshop, Katowice, Poland.
- [9] Pacyna, J.M., Munthe, J., Wilson, S., Maxson, P., Sundseth, K., Pacyna, E.G., Harper, E., Kindbom, K., Wangberg, I., Panasiuk, D., Glodek, A., Leaner, J., Dabrowski, J., 2008. Technical Background Report to the Global Atmospheric Mercury assessment. Arctic Monitoring and Assessment Programme/ UNEP Chemical Branch. [www.chem.unep.ch/mercury](http://www.chem.unep.ch/mercury).
- [10] Anna Glodek, Jozef M. Pacyna, Mercury emission from coal-fired power plants in Poland, *Atmospheric Environment*, Volume 43, Issue 35, November 2009, Pages 5668-5673, ISSN 1352-2310
- [11] Pacyna, E.G., Pacyna, J.M., Steenhuisen, F., Wilson, S., 2006. Global anthropogenic mercury emissions inventory for 2000. *Atmospheric Environment* 40, 4048-4063.
- [12] James M. Dabrowski, Peter J. Ashton, Kevin Murray, Joy J. Leaner, Robert P. Mason, Anthropogenic mercury emissions in South Africa: Coal combustion in power plants, *Atmospheric Environment*, Volume 42, Issue 27, September 2008, Pages 6620-6626, ISSN 1352-2310.
- [13] Damon Turney, Vasilis Fthenakis, Environmental impacts from the installation and operation of large-scale solar power plants, *Renewable and Sustainable Energy Reviews*, Volume 15, Issue 6, August 2011, Pages 3261-3270, ISSN 1364-0321.
- [14] Vasilis M. Fthenakis, Hyung Chul Kim, Erik Alsema., Emissions from Photovoltaic Life Cycles. *Environmental Science and Technology* 2008; 42: 2168-2174.
- [15] Ruud Meij, Henk te Winkel, The emissions of heavy metals and persistent organic pollutants from modern coal-fired power stations, *Atmospheric Environment*, Volume 41, Issue 40, December 2007, Pages 9262-9272, ISSN 1352-2310.
- [16] Jenny Nelson, Ajay Gambhir and Ned Ekins-Daukes., Solar Power for CO<sub>2</sub> Mitigation. Grantham Institute for Climate Change Imperial College London Briefing Paper no. 11.
- [17] Zhong Xiang Zhang, Asian energy and environmental policy: Promoting growth while preserving the environment, *Energy Policy*, Volume 36, Issue 10, October 2008, Pages 3905-3924, ISSN 0301-4215.
- [18] R. Saidur, N.A. Rahim, M.R. Islam, K.H. Solangi, Environmental impact of wind energy, *Renewable and Sustainable Energy Reviews*, Volume 15, Issue 5, June 2011, Pages 2423-2430, ISSN 1364-0321.
- [19] Kopp, G. and Lean, J.L. A new, Lower Value of Total Solar Irradiance: Evidence and Climate Significance, *Geophys. Res. Letters* Frontier article, 38, L01706, doi: 10.1029/2010GL045777, 2011.
- [20] World Energy Outlook, International Energy Agency (IEA) 2012.
- [21] Greenpeace International, European Renewable Energy Council GWE. 2012 Energy Revolution: a sustainable world energy outlook (<http://www.Energyblueprint.info>).
- [22] IPCC. Fourth assessment report of the International Panel on climate change: mitigation of climate change; 2007.
- [23] Sarada Kuravi et al. Thermal energy technologies and systems for concentrating solar power plants, *Progress in Energy and Combustion Science*, Volume 39, Issue 4, Pages 285-319.
- [24] John J. Burkhardt III, Garvin Heath, and Elliot Cohen, Life Cycle Greenhouse Gas Emissions of Trough and Tower Concentrating Solar Power Electricity Generation Systematic Review and Harmonization, *Journal of Industrial Ecology* 16, S1; DOI: 10.1111/j.1530-9290.2012.00474.x, 2012.
- [25] Ahmad Bilal Awan, Zeeshan Ali Khan, Recent progress in renewable energy – Remedy of energy crisis in Pakistan, *Renewable and Sustainable Energy Reviews*, Volume 33, May 2014, Pages 236-253, ISSN 1364-0321.
- [26] Kaffine Daniel T, McBee, Brannin J, Lieskovsky, Jozef ., Emissions Savings from Wind Power Generation in Texas, *The Energy Journal*, Volume 34, Issue 1, January 2013, Page 155.
- [27] R.H. Crawford, Life cycle energy and greenhouse emissions analysis of wind turbines and the effect of size on energy yield, *Renewable and Sustainable Energy Reviews*, Volume 13, Issue 9, December 2009, Pages 2653-2660, ISSN 1364-0321.
- [28] Ali Mostafaeipour, Productivity and development issues of global wind turbine industry, *Renewable and Sustainable Energy Reviews*, Volume 14, Issue 3, April 2010, Pages 1048-1058, ISSN 1364-0321.